



# JOURNAL OF THE ROYAL SOCIETY OF NEW ZEALAND

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ROYAL SOCIETY  
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**Successor to the  
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**Volume Twelve**

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# Journal of the Royal Society of New Zealand

Successor to the *Transactions of the Society* (1869-1971)

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# THE ROYAL SOCIETY OF NEW ZEALAND

Founded 1867 as the New Zealand Institute; name changed, 1933.

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## Publications

Volume 1 of the annual *Transactions and Proceedings of the New Zealand Institute* was published in 1869 (reprinted in revised form, 1875). The *Transactions* were published in quarterly parts from Volume 58 (1927-28) to Volume 88 (1960-61). A new volume numbering system and a division into sections (Zoology, Botany, Geology, and General) was instituted in 1961. In 1968, the number of sections was reduced to three (Biological Sciences, Earth Sciences, and General). Publication in this form, in which each paper was issued separately, was concluded at the beginning of 1971. This *Journal* is the successor to the *Transactions* of the Society and its predecessor, the New Zealand Institute. An author and title index to the complete run of the *Transactions* is available from the Society's offices (\$10; \$5 for members of affiliated societies).

The *Proceedings* of the Society (formerly included with the *Transactions*) have been published separately from Volume 85 (1958), the latest number being Volume 109 (for 1981), issued in 1982. They include a full account of the Society's activities, names and addresses of fellows and honorary members, personnel and reports of committees, the Council's annual report, annual reports of member bodies, details of the Society's medals and prizes with lists of medallists and prize-winners, trust and other funds, research grants and reports of grant recipients, occasional special articles, and obituaries. They also list the current honorary and paid officers of the Society. The Royal Society of New Zealand Act (1965), amending the 1933 Act, and the Rules adopted under the authority of the act were last published in the *Proceedings* for 1968-69; a current set of rules is available from the Society's offices.

*Bulletins* of the Society consist of works of scientific research that are considered unsuitable, because of size or content, for publication in the *Journal*. They are published at irregular intervals, subject to the approval of the council in each instance.

The Society also publishes a *Miscellaneous Series*, which in general includes reports of special committees established by the Society's council. These are also published at irregular intervals. This series also includes some conference proceedings and related material.

All members of the affiliated member bodies of the Society receive a *Newsletter* about four times a year.

Selected publications available from the Society are described on the inside back cover of this journal.

## An association of *Torlessia* and late Middle-early Upper Triassic fossils at Pudding Hill Stream, Central Canterbury

J. D. Campbell\* and I. J. Pringle\*

Marine invertebrates of late Middle-early Upper Triassic age are associated in redeposited sediments with tubes of *Torlessia* at Pudding Hill Stream near Mount Hutt, central Canterbury. Bryozoans, taxodont bivalves, *Plicatula*, brachiopods including *Mentzelopsis*, gastropods and crinoids are preserved in more or less fragmentary form in the coarse (granule-sized) bases of graded units, some of which contain *Torlessia* tubes in their finer-grained upper parts. The mode of occurrence suggests emplacement by subaqueous flow of both the tubes and the shelly remains. Contemporaneity of the tubes and the other fossils is certain and time equivalence of Pudding Hill Formation and Fingers Formation to the west is established. An east-facing palaeoslope seems likely for the Rangitata-Ashburton catchment area for at least part of Triassic time.

### INTRODUCTION

In the course of a field study of the clastic content of rocks of the Torlesse Supergroup by T. C. MacKinnon, the authors, as his field companions, collected *Torlessia* tubes and other fossils in boulders in scree in the catchment of the Ashburton River (North Branch), central Canterbury. Later investigation showed the two groups of fossils to be preserved within single alternations.

### PUDDING HILL STREAM OCCURRENCE

Pudding Hill Stream, a tributary of the Ashburton River (North Branch) drains the precipitous southeast flank of the Hutt Range (Fig. 1). Its steep middle course provides an almost continuous section through easterly-striking Torlesse Supergroup rocks in the form of stream bank exposures and some outcrops in the stream itself. A thick succession of thin-bedded redeposited sediments, generally with steep dips but locally involved in tight folds, forms the major part of the sequence. Hematitic metavolcanics occur in places. The whole can be accommodated in Pudding Hill Formation of Oliver (1979).

The most southeasterly kilometre of section includes a number of localities from which *Torlessia* tubes have been collected (Fig. 2).

It is within this sector that detailed measurement was made through a 20 m section (Fig. 3) at grid reference K36/904373 (S82/529107) about 2 km upstream of the irrigation intake, on the true left bank of Pudding Hill Stream.

The measured section can be regarded as representative of the succession as a whole. All features, including fossiliferous granule-sized bases in graded beds, are known from other parts of the section between the measured section and the plains (T. C. MacKinnon, pers. comm.).

Fossils other than *Torlessia* tubes are found in the bases of graded beds, along with granule-sized (and larger) intraformational clasts of sandstone and siltstone. The fossiliferous, graded units, apart from parallel laminations and occasional small sandstone concretions in their finer regions, are otherwise structureless. Descriptions of a typical graded unit, along with an underlying unit containing *Torlessia* tubes, is given in Figure 3. These can be regarded as representative of other fossil-bearing units.

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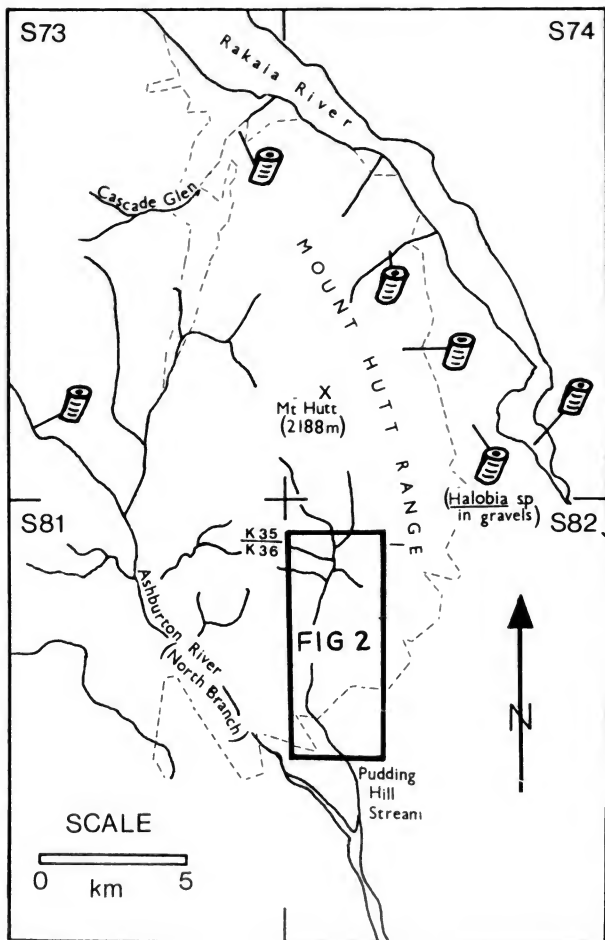


Fig. 1—Location map.

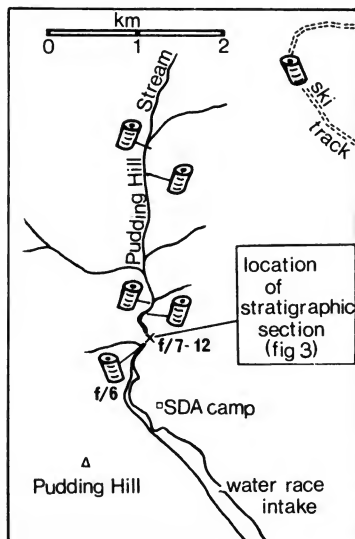


Fig. 2—Detailed sketch-map of Pudding Hill Stream area, with locations of fossil localities K36/f6 and f7-12.

Note: On Figures 1 and 2 *in situ* localities for *Torlessia* from Campbell and Warren (1965) are shown by the symbols tilted to the right. *In situ* localities reported in this study are shown by symbols tilted to the left.

Plant material in the form of flattened stems (less than 3 cm × 30 cm long) is present near the bases of some of the coarser grained units, 30 m upstream of the measured section.

## FAUNA

### Fauna of the coarse-grained bases of graded units

*Nuculana* cf. *semicrenulata* (Trechmann)  
*Plicatula* sp.  
*Mentzeliopsis* sp.  
 spiriferinid  
 rhynchonellide  
*Dielasma* sp.  
 bryozoans  
 crinoid columnals

Preservation is generally indifferent, most shells being fragmentary and in a rather impaired condition. The fauna includes both infaunal and epifaunal elements. Bryozoans, preserved as encrustations on bivalve shells, show that the present association in one fossil assemblage is not entirely fortuitous. Indeed, the assemblage as a whole may represent the skeleton-bearing organisms of one community. There are no deep-water or intertidal forms present and a shelf derivation seems likely.



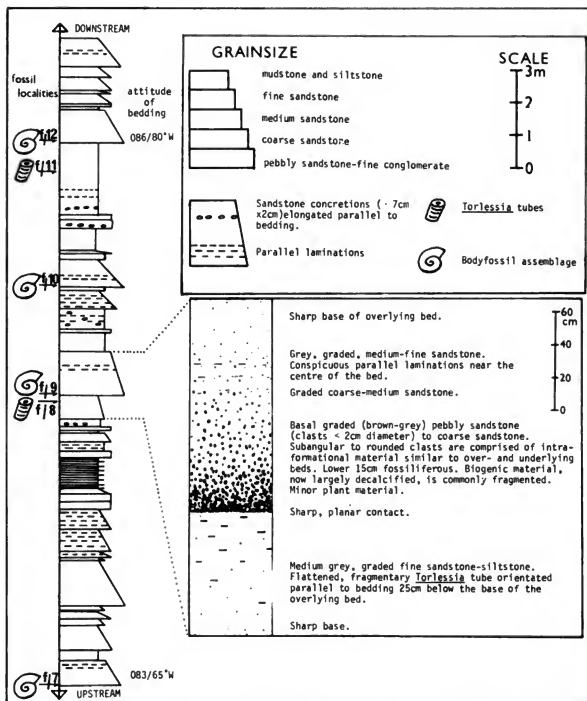


Fig. 3—Stratigraphic column at K36/904373, Pudding Hill Stream.

Although the fauna does not include any form that is known to be closely restricted in time, the presence of *Mentzeliopsis* is indicative of the pre-Otamitan local stage of the New Zealand Triassic System. Further, *Plicatula* sp. from Pudding Hill Stream cannot be separated from a form from the Fingers Formation, Old Man Range (Locality S81/f559, see Beggs, 1981; Oliver, 1979) where it is associated with *Spiriferina* cf. *abichi* Oppel which is not known to occur outside the range Kaihikuan-Oretian. The age cannot be more closely determined than late Middle-early Upper Triassic.

#### Fauna of the finer-grained parts of the graded units

##### *Torlessia mackayi* Bather

The tubes found in and near the measured section are short, presumably broken, specimens. They have random orientation with respect to bedding. Although the precise

habitat of *Torlessia* is unknown, a benthic infaunal environment is favoured by many workers (e.g. Stevens, 1972). The occurrence of tubes at Pudding Hill Stream provides no direct evidence of station during life. It does, however, require the operation of a mechanism whereby granule and sand/silt fractions of individual beds could contain shelly fossils and fragmented tubes respectively without intermixing. A possible explanation involves derivation of the two faunas from different sources or habitats. A single mass-deposited unit may have incorporated material from numerous locations along its path during deposition. In the downslope journey, perhaps, the components were separately gathered but never fully mixed. The finer portion was presumably incorporated from a deeper water station than that of the granule-sized material.

Absence of many sedimentary structures typical of 'Bouma' graded beds (e.g. sole markings, cross laminations) in the fossil-bearing strata indicates that deposition mechanisms and perhaps transport mechanisms differed from those producing more 'normal' graded units.

The age of *Torlessia* has plagued workers in the older rocks of New Zealand for 120 years. Preferred 'ages' have been published by Jaworski (1915), Campbell *et al.* (1960), Webby (1958), Campbell and Warren (1965), Stevens (1972), Speden (1975), Andrews *et al.* (1976), and Stevens and Speden (1979). There has never been unreserved acceptance of these circumstantially-derived estimates (cf. Gage, 1970). It was a noteworthy event, therefore, when Force and Force (1978) were able to show that a single structural block at Black Forest, South Canterbury, contained both *Torlessia* tubes and a shelly fauna including the Etalian-Kaihikuan bivalve, *Daonella*, albeit 5 km apart. Their mapping suggested lateral equivalence of the two faunas. The present study supports this contention in that the graded units at Pudding Hill Stream contain both *Torlessia* tubes and a late Middle-early Upper Triassic fauna deposited simultaneously.

## CASCADE GLEN OCCURRENCE

Fleming (Campbell and Warren, 1965) recorded an occurrence of an aptychus with *Torlessia* from Cascade Glen, near Redcliffe, Rakai Valley (Fig. 1). This had the importance of establishing an association of *Torlessia* and a 'shelly' fossil. The occurrence offers little information about the biology of *Torlessia* but further examples of aptychi and tubes have been collected there, and the search for cephalopod conchs should be continued.

Tube-bearing siltstone at Cascade Glen has at least two kinds of trails preserved on bedding surfaces. Forms resembling Helminthoidea and Urohelminthoidea are present. Clearly there was a soft-bodied benthic fauna in the site of accumulation of sediment. By contrast with the Pudding Hill Stream occurrence, *Torlessia* tubes are commonly of large size and they show little sign of extensive transport after death.

Largely intraformational conglomeratic material forms an apparently massive unit overlying the *Torlessia*-bearing siltstones. To date the only fossil found in the conglomerate is a *Torlessia* tube which occurs in a siltstone clast. It appears to indicate derivation of tube-bearing siltstone from an upslope source.

By virtue of the preponderance of thin-bedded material of mostly silt grade, the Cascade Glen occurrence is accommodated in Pudding Hill Formation. Although exact time-equivalence of Cascade Glen and Pudding Hill Stream occurrences is not established, broad lateral equivalence is probable. If the two occurrences represent the products of the same mechanisms of transport and deposition, Cascade Glen is the more proximal.

## IMPLICATIONS IN REGIONAL STRATIGRAPHY

Before this study was begun, Oliver and Beggs had developed the notion of a broad lateral equivalence of lithostratigraphic units within the Torlesse Supergroup in the Rangitata-Ashburton catchment areas. Mount Potts Group of Kaihikuan and Oretian age and the Fingers Formation of Kaihikuan and perhaps Oretian age were ranged alongside the Pudding Hill Formation which, although containing abundant tube-fossils, could not at the time be ascribed any precise age on internal (faunal) evidence. The

present work provides an estimate of age and the notion of lateral equivalence is enhanced.

The region also includes rocks that are younger (Clent Hills Group of Oliver, 1979) and some that are probably older (e.g. Torlesse Supergroup, undifferentiated as at Mount Potts (Campbell and Force, 1972)) than these three. It is interesting to note that the occurrence of *Halobia* in fan gravels in the Rakaia River below Blackford Station (Campbell and Warren, 1965) provides an Oretian age for siltstone of presumed local derivation within the Hutt Range.

In our view it is premature to attempt large-scale palaeogeographic reconstructions of Torlesse geology for New Zealand or even for Canterbury, yet we are prepared to assert that some facts of early Mesozoic palaeogeography of the central Canterbury region are known. As suggested by Campbell and Force (1972), shallow water existed in Kaihikuan and perhaps Oretian time west of the present Taylor and Hutt ranges. In the latter area, offshore, probably deep conditions prevailed (Oliver, 1979; this paper). Beggs (1981) has demonstrated water depth of an upper or middle submarine fan for the intermediate area, that now occupied by the Taylor Range. The already good case for an easterly facing palaeoslope seems to be strengthened.

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## Oligocene unconformities and nodular phosphate — Hardground horizons in western Southland and northern West Coast

R. M. Carter\*, J. K. Lindqvist,\*\* R. J. Norris\*\*

Oligocene strata generally occur as paraconformable or condensed sequences in the New Zealand region. Descriptions are given of well-exposed sections through Oligocene unconformities in the Waiau River (western Southland) and at Whitecliffs, Buller River (northern West Coast). In both cases the unconformities are preserved in sediment sequences of inferred basin-margin origin with respect to contemporaneous, Oligo-Miocene, fault-controlled basins. At Whitecliffs, an early Oligocene angular unconformity separates the regionally transgressive Maruia Group below from the more locally transgressive, mid-late Oligocene Cobden Group (Whitecliffs Formation) above; abundant fresh detritus from the Maruia Group occurs in breccias associated with the Cobden Group, which is separated from the overlying early Miocene Blue Bottom Group (Inangahua Formation) by a further unconformity, marked by a condensed sequence shellbed with rolled, phosphatized and glauconitized macrofossils and abundant pelagic microfauna. The shellbed has a hardground contact at its base, resulting in the incorporation of phosphatized intraclasts of Cobden Group limestone into the nodular phosphate shellbed. A similar nodular phosphate shellbed marks the contact between the Tunnel Burn limestone or Point Burn sandstone and the Garden Point mudstone in the Waiau River section in Southland, though diagenesis, particularly solution of the top of the limestone, has obscured some sedimentary detail. The phosphate present at both localities is in the form of shell replacements and mineral cements. The phosphatic nodular layers are difficult to date accurately, but probably both the Westland and Southland occurrences are mid-late Oligocene (Ld-Lw) and therefore of similar age to the Marshall Paraconformity. A type locality for the Marshall Paraconformity, at Squire Farm, south Canterbury, is proposed in an appendix.

### INTRODUCTION

The presence of Oligocene unconformities in the New Zealand region has been widely remarked on (Speight and Wild, 1918; Carter and Landis, 1972; Kennett *et al.*, 1974). There are, however, no detailed modern descriptions of these regionally important features. This paper presents a description of two recently studied sedimentary sections in which Oligocene unconformities occur, one in western Southland, the other in northern Westland (Fig. 1).

### WESTERN SOUTHLAND

The Kaikoura sedimentary sequences of western Southland are poorly known, apart from the detailed study by Wood (1969) of the Clifden area. Papers by McKellar (1956), Grindley (1958), and Mutch (1972) contain reconnaissance data, and Carter and Norris (1977) present a brief description of the geology of the Blackmount area, at the north end of the Waiau Basin. The regional sedimentary history has been summarized by Turnbull *et al.* (1975) and Norris *et al.* (1978). Formations used in the description below were informally introduced by Carter and Norris (1977), and will be formally defined in a publication at present in preparation.

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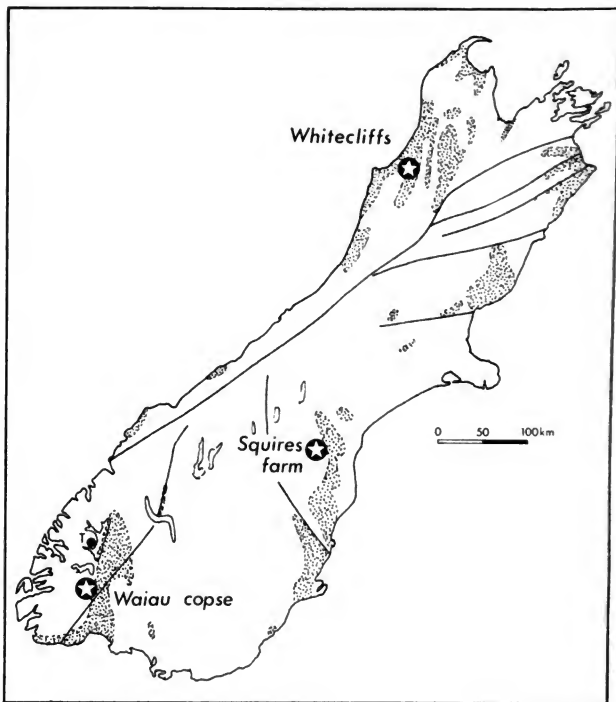


Fig. 1—Locality map (T, Te Anau locality, Fig. 3).

### Sedimentary setting

The post-Eocene marine sedimentary sequence at Blackmount (Fig. 2) is at least 6 km thick and has been divided into five formations. The Blackmount Formation, 2–3 km thick, grades from mass-emplaced breccias and sands of inferred submarine fan origin at the base, to muddy turbidites and hemiterigenous mudstones of inferred basin-floor origin at the top. The lower parts of the formation are of unsuitable facies for fossil preservation, but are probably early to middle Oligocene (upper Lwh); the upper parts of the formation contain rich planktic faunas of middle to late Oligocene age (Lwh, Ld, and lowest Lw). The Blackmount Formation is followed by the McIvor Formation, a 100–200 m thick early Miocene calciflysch. Further thick formations follow above (Fig. 2), both the facies and overall thickness suggesting that the Blackmount sequence accumulated in an active, fault-controlled basin (cf. Norris *et al.*, 1978).

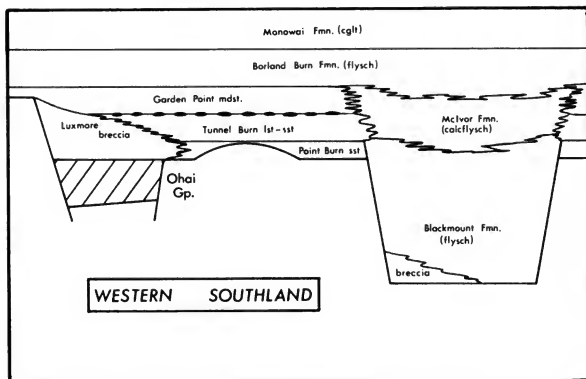


Fig. 2—Diagram of Kaikoura Sequence sedimentary units, western Southland.

### Basin margins

**West side Te Anau Basin.** McKellar (1956) has described a sequence on the west side of the Te Anau Basin (Fig. 1) that comprises sandstone and shale (Point Burn Formation) overlain by marine limestone (Tunnel Burn Formation), mudstone (Garden Point Formation) and sandstone. The sequence has been revisited and measured (Fig. 3).

The Point Burn Formation is of marginal and shallow marine origin, as indicated by trace-fossils, cyclic sediments and the presence of the calcareous algae *Lithophyllum*, *Lithothamnium* and *Lithoporella* (Fig. 4b). A breccia-bed and herringbone cross-bedded sands occur at the base of the lakeshore section. The overlying bioclastic limestones and associated quartzo-feldspathic sandstones of the Tunnel Burn Formation are generally massive. The commonest sedimentary structure is large-scale cross-stratification (Fig. 4a) which, together with rubbly shell-beds, is consistent with an inshore marine or "shelf" origin. Locally, and particularly at the top of the limestone, *in situ* algal rhodoliths up to a few centimetres across occur. The top of the limestone has solution pipes penetrating down from above, containing pebbles of limestone and rhodoliths set in a firmly cemented calcareous sandstone matrix; the matrix merges up into a c.50 cm thick sandstone at the base of the Garden Point Formation. The bulk of the Garden Point Formation comprises massive mudstone with abundant planktic foraminifera (early Miocene, Pl), passing up into redeposited sandstones here included in the Borland Burn Formation.

**Interpretation:** A major change in sedimentary facies takes place across the Tunnel Burn/Garden Point Formation contact, from shallow marine tractionites below to deep marine, suspension-emplaced mudstone above. This change, and the development of a nodular layer at the contact, is not part of a gradual Waltherian sedimentary cycle but was rather caused by extraneous factors such as sudden regional subsidence or eustatic sea-level change. Before the marked deepening, clastic sedimentation had been reduced to a minimum, probably with the development of a sea-floor omission surface. Evidence from farther south (see below) suggests that this surface may have been a hardground at the top of the Tunnel Burn Limestone, but at Lake Te Anau the details of the contact have been obscured by later solution. The limestone clasts and rhodoliths at the contact are residual, i.e. derived by solution from the limestone below. Grains at the clast margins

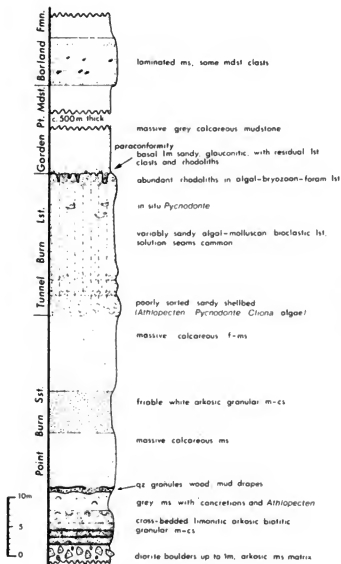


Fig. 3—Measured section through Cenozoic sediments, west side of Te Anau Basin (S140/745298, north side, South Fiord, Lake Te Anau).

are truncated, there is a concentration of limonite-stained, insoluble clay and sand at their periphery, and pyrite is oxidized only in the outer parts of the clasts (OU 37601-2). The sandy matrix to the nodule bed is also clearly a solution residue, comprising a texturally messy concentration of corroded bioclasts and terrigenous grains, all rimmed by brown staining solution seams (OU 37603). Though much solution may considerably post-date deposition of the nodular bed, the presence in the matrix of glauconite and well-preserved *Globigerina*, the latter more abundant upwards (OU 37604), suggests that appreciable solution pre-dated the deposition of the Garden Point mudstone, taking place either on the sea floor or perhaps subaerially during a eustatic sea-level minimum (cf. Vail *et al.*, 1977).

**West Side Waiau basin.** A sequence closely similar to that of Takahe Valley-Te Anau is exposed on the west side of the Waiau Valley, on the NZED access road to the Borland Saddle. Definitely non-marine sediments are again not seen, though the lowest sands exposed are carbonaceous and the lowest few tens of metres of the Kaikoura sediments are not exposed. The sequence is of similar facies and thickness to the Point Burn and Tunnel Burn Formations in their type area, with well-developed herringbone cross-stratification in the Point Burn quartzo-feldspathic sands. Beds above the Tunnel Burn Formation are not seen, and the Borland Road sequence is in fault contact to the east with deep marine, middle Miocene mudstones that correlate with the Duncraigen Formation of the Blackmount sequence.

A little farther north, and on the other (eastern) side of the Fiordland boundary fault,



Fig. 4—(a) Tunnel Burn Formation, on ridge between Point Burn and Takahe valleys; view east. Rhythmically bedded algal-molluscan calcarenites, overlain by arkosic sands (large-scale cross-beds, arrowed), and flaggy bioclastic limestones.



(b) Detail of *in situ* rhodoliths (location ringed on Fig. 4a), comprising intergrowths of *Lithothamnium* and *Lithoporella* with associated *Lithophyllum* (OU 39929).

an additional outcrop of the basin margin sequence occurs in the western banks of the Waiau River, opposite a beech copse and about 2 km north of the Redcliff Stream junction (grid reference S58/703887). This previously inaccessible locality can now (i.e., since the construction of the Mararoa control structure) be reached by wading directly across from the eastern bank of the Waiau. The sediments are well exposed in river-cut outcrops on the west side of the river and in a small stream that drains into the Waiau from the west.

#### Waiau beech copse locality

**Stratigraphy.** The stratigraphy (Fig. 5) is similar to that described from the Borland Road and Takahe Valley, though the basal contact is here (uniquely) exposed.





The pre-Kaikoura Sequence unconformity is exposed on the north bank of a small stream, a few tens of metres up from its confluence with the Waiau River at grid reference D44/922908. Basement granite outcrops as a small waterfall in the creek, the upper 2–3 m being increasingly leached towards the unconformity. A carbonaceous, jarositic siltstone with ripple cross-lamination occurs at the base of the sedimentary sequence, followed by 30 cm of friable, micaceous, quartzo-feldspathic, medium to coarse sand. The beds dip at about 50° to the southeast. The next 20–30 m of section is obscured, but similar non-marine, carbonaceous, quartzo-feldspathic, cross-stratified sand and associated carbonaceous, micaceous shale occurs at the base of Section 2 (Fig. 5), passing upwards into biotitic sand which towards the top contains scattered algal fragments, molluscan shell fragments and limonite-walled thalassinidean burrows. These unlithified sediments of the Point Burn Formation pass up in turn into a thin cemented calcareous sandstone with scattered algal colonies or into sandy to pure, crystalline, algal limestone of the Tunnel Burn Formation (Sections 3–4).

A nodular shellbed occurs above the Tunnel Burn Formation (described in more detail below), followed by a rapidly deepening sequence which over 30 m passes from muddy, glauconitic calcareous sandstone, through sandy and glauconitic mudstone to massive, chippy-weathering hemiterrigenous calcareous mudstone (Fig. 6). These sediments are here included in the Garden Point Formation. The first redeposited sandstone beds occur about 50 m higher in the sequence, and mark the base of the thick terrigenous flysch of the Blackmount column (cf. Fig. 2).

**The Tunnel Burn-Garden Point contact.** The contact between the Tunnel Burn and Garden Point Formations has the characteristics of a condensed sequence, best seen at Sections 3 and 4. The top of the limestone is irregular and has anastomosing cracks and crevices penetrating down from above. Resting on the limestone and filling these cracks is a layer of *Type 1 nodules* set in a scaley matrix of sandy, glauconitic, pyritic clay. Individual Type 1 nodules are generally 3–10 cm in diameter, irregular in shape and often knobby (Fig. 7a). They are composed of extremely hard, recrystallized algal limestone.

At the south end of the outcrop, at Section 1, the Tunnel Burn Formation is absent, the Garden Point Formation resting directly on a cemented sandstone at the top of the Point Burn Formation (Fig. 6). The contact is again marked by a nodular layer, in this case

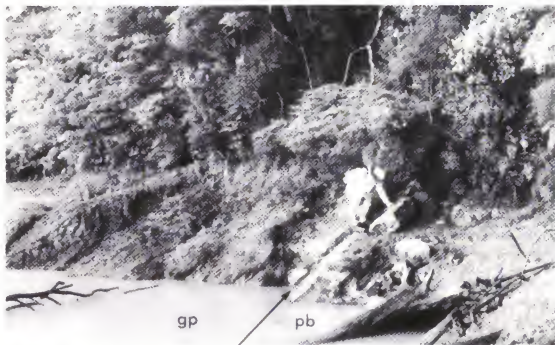
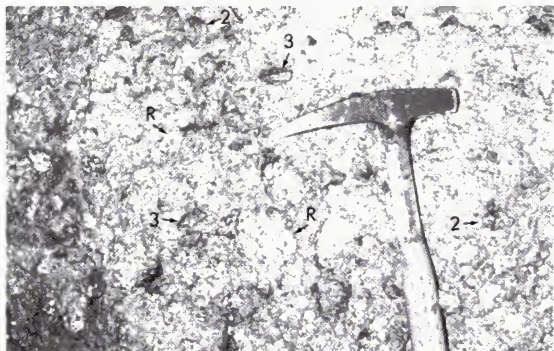


Fig. 6—(a) Outcrop view of Point Burn-Garden Point contact, nodular bed arrowed (Section 1, Fig. 5).



(b) Detail of nodular phosphatic horizon. Rhodoliths (R) and phosphate nodules Types 2 and 3 indicated.

comprising (1) *Lithophyllum-Lithothamnium* rhodoliths up to 3 cm in diameter (Fig. 7b); (2) *Type 2 nodules*, phosphatized steinkerns or internal moulds of invertebrate shells (Fig. 7b) or trace fossils; and (3) *Type 3 nodules*, irregularly shaped nodules 0.5-2 cm across (Fig. 6b), probably derived from Type 2 nodules by sea-floor breakage and erosion.

**Details of nodule preservation.** *Type 1 nodules* are generally grey due to the presence of dispersed pyrite, which is also present as cubes up to several millimetres across. The main body of nodules is non-glaucinitic, but a thin, flakey layer of glauconite often occurs as a skin or as a lining to micrite- and/or phosphate-filled borings. A thin crust of calcite may be superimposed on the glauconite skin, and also occurs encrusting the rare, well rounded, terrigenous pebbles present in the nodular bed.

The *rhodoliths* are concentrically layered intergrowths of algae, variously nucleated on shell fragments or on small pieces of dark grey algal biomic sparite. Successive stages of rhodolith growth are defined by discontinuities in layering and by the presence of several generations of endolithic borings filled with detrital micrite. Minor growth voids are filled, sometimes geopetally, by micrite and/or by late stage coarsely crystalline spar cement. Commonly the last stage of growth is represented by a rim of creamy white algal material a few millimetres wide (contrasting with the earlier growth, most of which is grey because of abundant intracellular pyrite). This white rim is penetrated by the latest generation of borings, which are filled by creamy-yellow phosphate cement, and/or by detrital micrite; these phases post-date an early fibrous calcite cement which rims the walls of some borings (OU 44316).

There is a complex range of *Type 2 nodules* from apparently unaltered shells with phosphatized internal fillings to barely recognizable fragments of phosphatized internal moulds. Preservation is good, with fossils being undeformed by compaction (Fig. 7b). Significant points include:

- (1) Shell material may be present on aragonitic (bivalves, gastropods, coelenterates) and calcitic (brachiopods, pectinid bivalves, algae) taxa but is most common for calcitic forms; either type may alternatively be preserved as phosphatized steinkerns.
- (2) Calcitic shells are preserved as original or neomorphic calcite; aragonitic forms have the shell replaced by varying combinations of phosphate, glauconite and pyrite.
- (3) Epizoans occur in two main ways: (a) as borings in calcitic or replaced aragonitic

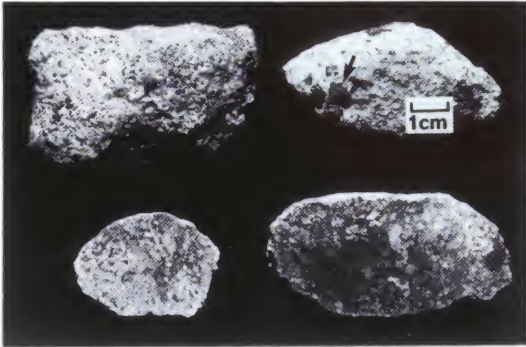
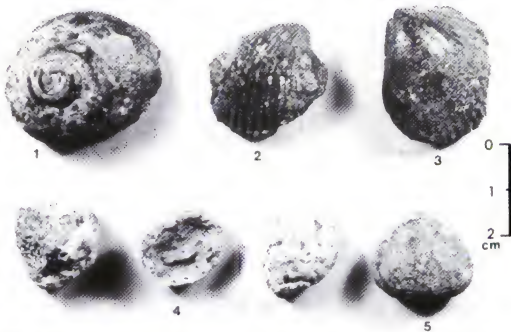


Fig. 7—Phosphate nodules and fossils from the nodular phosphatic horizon. (a) Type 1 nodules with large pyrite crystals (arrowed) (Section 4).



(b) Phosphatized fossil steinkerns and algae, nodular bed, Section 1: 1. *Turbo* (*Modelia*) 2. *Venericardia* 3. *Lima* 4. algal rhodoliths 5. *Tegulorhynchia*.

shells (this generation of borings can also be recognized as traces on internal moulds from which the shell was later dissolved); and (b) as borings in, or positive relief internal moulds superimposed on, phosphatized internal moulds from which the shell had been dissolved before epifaunal encrustation or endolithic penetration. The fill of endolithic borings comprises a variable and complex mixture of clastic sediment and authigenic phosphate, glauconite, pyrite and calcite spar; there may be more than one generation of borings recognizable from cross-cutting relations.

**Petrography:** (i) Terrigenous. The terrigenous mineralogy of all sediments within the Point Burn, Tunnel Burn and Garden Point formations is similar, and largely of granite provenance (OU 44302-44305; Fig. 8a). Detrital grains are generally fresh, comprising microcline, orthoclase-perthite, plagioclase and quartz, with accessory biotite (occasionally present in amounts of 10% or more—OU 44303), sphene and epidote in grains as large as coarse sand, and finer grained and rarer apatite, hornblende, magnetite, zircon and muscovite. The sediments are arkosic, with feldspar contents of up to 30%+ of the clasts (OU 44304, visual estimate); felsic grains in the basal Point Burn sands are more poorly sorted and angular than those higher in the section and include many composite grains with conspicuous internal fractures (Fig. 8a).

Occasional 2-8 cm diameter well-rounded terrigenous pebbles occur within the nodular layer at the base of the Garden Point Formation (OU 44319). They are in general not of immediately local provenance, comprising hornfels, quartzite and slate pebbles of southern Fiordland origin, one granite pebble, one andesite pebble, and one greywacke pebble of Torlesse type, the latter presumably derived from far to the northeast.

(ii) Bioclastic. The upper part of the Point Burn sandstones contains small amounts of dispersed fossil material (e.g. Sections 2, 3; Fig. 5), locally being cemented by dusty, poikilotropic calcite in which the terrigenous grains occur in grainstone support (OU 44304). With increasing bioclastic content, such sediments grade laterally and upwards into sandy and pure limestones of the Tunnel Burn Formation. Typical Tunnel Burn Limestone (OU 44305-10) is a packstone of calcareous algae (*Lithophyllum*, *Lithothamnium*) and large benthic foraminifera (*Amphistegina*, *Gyroidinoides*) (Fig. 8b); other bioclasts include bryozoa, echinodermata, mollusca, and annelida. There are variable amounts of fresh terrigenous sand or silt, up to 50% in parts of the formation (OU 44305). Some algal fragments probably represent *in situ* growths, reaching 1 cm or more across, but most algal and other bioclasts are broken fragments. Bioclasts have embayed margins and often are penetrated by other clasts — a result of pervasive pressure solution (Fig. 8b). (Larger-scale solution seams are conspicuous in outcrop, delineated by micas and clay grade insolubles.)

The walls of most bioclasts lack fine structural detail because of neomorphic recrystallization. Bioclast cavities are filled with microspar (rarely micrite), which also occurs as the intergranular cement phase. Echinoderm grains have corroded syntaxial rims, but other early cements are generally absent. Late-stage, clean, coarse sparite veinlets cut the whole rock (OU 44305).

(iii) Authigenic and diagenetic. *Type 1 nodules* (OU 44318) have a similar clastic and cement composition to the Tunnel Burn limestone, some being essentially unaltered apart from penetration by peripheral borings (OU 44318a); others show moderate (OU 44318b) or substantial amounts of bioclast resorption with consequent overpacking of grains, concentration of insoluble terrigenoclasts and a conspicuous increase in pyrite (particularly along grain boundaries, though the larger aggregates transect grains and matrix alike — cf. Fig. 7a). Irregular surfaces of discontinuity occur within the nodules, apparently separating areas that have undergone differing amounts of solution and compaction. There is sometimes a marked change in pyrite content across these intranodular surfaces and also concentration of the pyrite along the surface, which then has the appearance of a solution surface against which bioclasts are truncated by resorption (OU 44318b). Phosphate does not occur within the main body of the nodules but only within peripheral borings, which are of two main types. The latest borings are infilled with micrite, glauconite and terrigenoclastic grains similar to the matrix of the bed; earlier generations of borings are generally filled with phosphate-cemented sediment similar to that of nodule Types 2-3 (OU 44318a). In some cases, nodules are so extensively corroded by boring that there may be the appearance of phosphate cement within the nodule (OU 44319), but in no case can such a cement be proved to occur within the nodule rather than within a boring. The phosphate cement post-dates a calcite scalenohedral rim cement (cf. Fig. 9d), but the lack of compaction of contained clastic grains nonetheless argues for an early, probably sea-floor, origin for the phosphate.

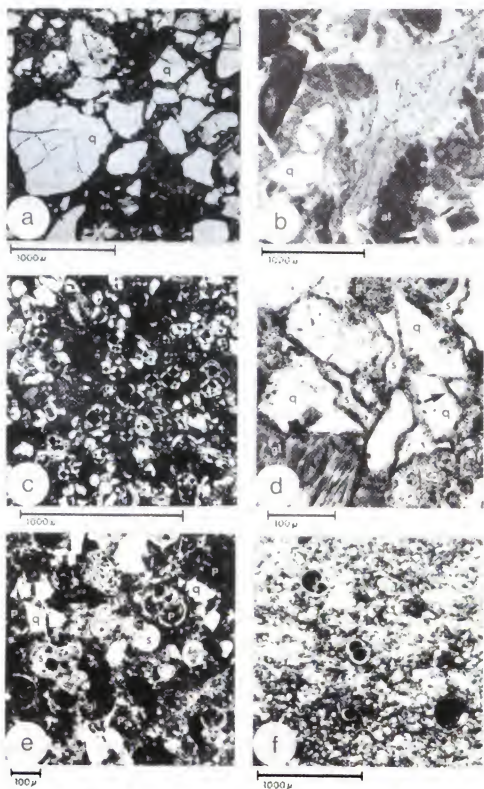


Fig. 8—Photomicrographs, Waiau River section. Abbreviations: q, quartz; al, calcareous algae; f, foraminifera; gl, glauconite; p, phosphate; s, sparite; sc, scalenohedral calcite. (a) Point Burn Sandstone (OU 44312); poorly-sorted quartz grains in sparite cement; (b) Tunnel Burn Limestone (OU 44307); overpacked algal and foram biocasts in sparite cement; (c) Type 2 phosphate nodule (OU 44313a); terrigenoclastic silt and abundant *Globigerina* in microcrystalline phosphate cement (crossed-nicols); (d) Type 2 phosphate nodule (OU 44314); phosphate rim cement (arrowed) on terrigenoclasts, remaining voids sparite or phosphate filled; (e) varied chamber fills in *Globigerina* in phosphate cement (OU 44313a); (f) Garden Point mudstone (OU 44325); pyrite-filled *Globigerina* set in silty mudstone.



The matrix to Type 1 nodules (OU 44320) contains terrigenous grains and extremely corroded bioclasts (mostly algal and foraminiferal) set in a matrix of dirty microspar containing abundant framboidal pyrite (up to 30%) and glauconite (up to 10%). As at Lake Te Anau, it is largely a residual deposit, formed by the concentration of insoluble minerals present in the parent limestone.

The matrix to the nodular bed at Section 1 (OU 44312) is closely similar to the subjacent cemented top of the Point Burn Formation (OU 44311). Granite-derived terrigenous grains, random microcrystalline and occasional vermicular glauconitic grains and bioclasts are set in a muddy microspar cement. Bioclasts are dominated by the planktic *Globigerina*, but there are also some deeply corroded bioclasts of benthic forms similar to those of the Tunnel Burn limestone, which, together with the presence of rare limonite-stained solution seams, suggests that at least the terrigenous parts of the matrix are a residual concentrate.

*Type 2 and Type 3 nodules* are petrographically similar to each other. Beautifully preserved bioclasts, and terrigenous silt and glauconite, are set in grainstone support in a cement of brown, microcrystalline phosphate (Fig. 8c), a mottled appearance in plane-polarized light reflecting minor admixtures of micritic and terrigenous mud throughout the cement (OU 44313-4). Several phases of cement are recognizable in some slides (OU 44313a), and X-ray diffraction shows that the phosphate is present as carbonate apatite, i.e. francolite. *Globigerina* is the dominant microfossil and is preserved with uncrushed tests, the chambers of which are variously infilled with phosphate, pyrite glauconite and sparry calcite (in that order of crystallization) (Fig. 8c). Some Type 2-3 nodules are rich in pyrite, or contain areas where an initial phase of phosphatization is preserved as a rim cement (OU 44314; Fig. 8d).

(iv) Paragenesis of the nodular layer. The nodular layer is the end result of a complex series of syn- and post-depositional dissolution, precipitation and replacement events. Though detailed paragenesis varies from one nodule to another, general paragenetic sequences can nonetheless be established (Table 1). It is, however, essential to clearly separate the interpretation of Type 1 nodules from that of Type 2-3 nodules.

*Type 1 nodules* are residual clasts of Tunnel Burn limestone. As such, their early paragenesis is that of the limestone. Because of later pressure solution, early cements are not well preserved in the limestone, but syntaxial rims, albeit corroded, are widespread on echinoderm grains, and very rarely other bioclasts preserve small patches of an early fibrous or scalenohedral rim cement. As suggested by the presence of a similar cement fringing bioclasts in the (early) phosphate cemented peripheral borings to Type 1 nodules (cf. Fig. 9d), such a rim cement was probably widely developed (before its destruction by compaction and solution). Though obscured by later diagenesis, the available petrographic evidence is therefore consistent with early cementation of the framework elements of the Tunnel Burn limestone, probably on or just beneath the sea floor (cf. Shinn, 1969), but possibly during a phase of emergence.

The production of Type 1 nodules from this parent, early cemented limestone is not understood in detail. However, the general stratigraphy and interpretation of the sequence indicate that both the limestone and the nodular layer have undergone a similar burial history, eventually being covered by several kilometres of overburden. It therefore seems unlikely that differences in degree of pressure solution between the nodules and parent limestone are due to differing overburden loads. Rather, we favour differences in solution chemistry, consequent upon the differing permeability of the two layers, as the best explanation. Before the deposition of the main cavity-filling sparite cements, the limestone may have remained permeable, allowing the free removal of phases such as FeS in pore water; by comparison, FeS and other insoluble residual material may have been 'trapped' by the impermeable mud matrix at the boundaries of the nodules or at major solution seams within them. Some support for such an interpretation comes from the concentration of pyrite of probable residual solution origin along the surfaces of Ordovician hardgrounds in Minnesota (Prokopovich, 1955), as a peripheral phase of a Jurassic hardground from England (Hallam, 1969), and as rims to Liassic hiatus concretions from Germany (Voigt, 1968), since in all these cases the pyritized

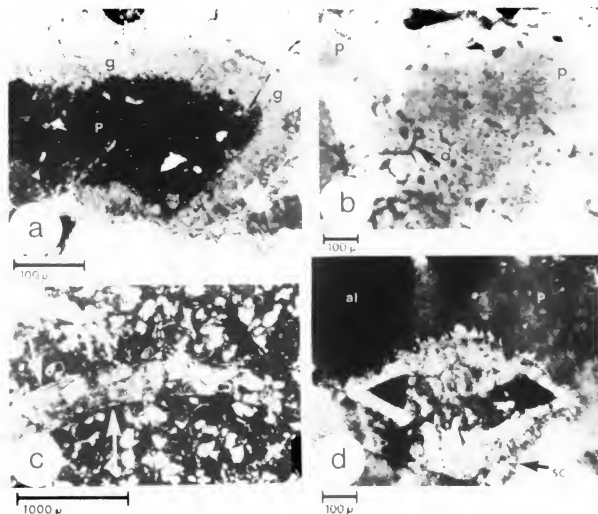


Fig. 9—Photomicrographs, phosphate nodules, Waiau River section (abbreviations as for Fig. 8): (a) glauconite-rimmed phosphate nodule (OU 44312); (b) pyrite-filled algal borings in phosphate cement (OU 44315); (c) phosphate envelope peripheral to shell fragment (arrowed); later infilled by sediment and itself phosphate cemented (OU 44313); (d) scalenohedral rim cement on foraminiferal bioclast, predating main phosphate cement (OU 44315).

hardgrounds are associated with overlying argillaceous or otherwise impermeable sediments. Not all of the pyrite in the Type 1 nodules necessarily originated as a solution residue. Together with pyrite that occurs as rim cement in peripheral borings in algal rhodoliths and Types 2-3 nodules, some of the pyrite probably represents original biochemical concentration, by reduction of  $\text{SO}_4^{2-}$  ions from pore water of sea water; Aller (1978) has demonstrated that major concentrations of FeS occur at the tube walls of the modern polychaete *Amphitrite*, and similar conditions quite possibly obtained within organic borings in the limestone nodules.

Irrespective of the precise origin of the pyritization, Type 1 nodules were undoubtedly present as clasts on the sea floor before the deposition of the Garden Point mudstone, as shown by their marginal borings with glauconitic, phosphatic and micritic fill. As this requires that the limestone was sufficiently lithified to have provided the clasts, it thereby also suggests that its top surface was a burrowed or bored hardground surface. The paragenesis of the fill of the borings is generally similar to that of the Type 2-3 nodules (see below).

*Type 2-3 nodules* comprise replaced fossil shells and their phosphate-cemented moulds from which the shell has then sometimes been dissolved. Very similar phosphate nodules have been described previously, for instance by Tourtelot and Cobban (1968) and by Kennedy and Garrison (1974). As in these, Type 2-3 nodules contain unequivocal



evidence for multiple phases of alteration and phosphatization, and for a sea-floor occurrence of these events:

(1) The presence of phosphate in two main guises, first as a replacement of the carbonate of bioclasts, and second as a rim and cavity-filling cement (cf. Fig. 8d).

(2) The presence of immaculately preserved microfossils, which shows that phosphate cementation took place before any compaction (Figs. 8c, e).

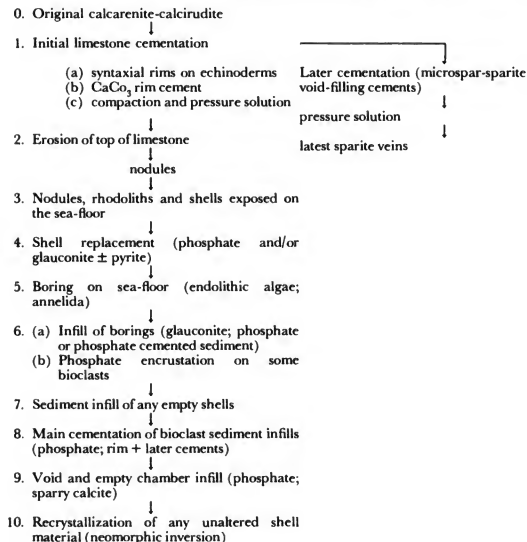
(3) The presence of small eroded chips of phosphate nodule, either with glauconite rims (Fig. 9a) or with peripheral borings infilled with later glauconite-cemented clastic detritus (OU 44312a), thus demonstrating the sea-floor origin of the phosphatization.

(4) A sea-floor origin is reinforced by two further observations: first, some phosphate-replaced shell fragments and phosphate cements contain probable algal borings, filled with pyrite (Fig. 9b); and second, the internal moulds of some gastropods are preserved with the shell represented by a phosphate 'envelope', infilled with terrigenous detritus set in a later phosphate cement (cf. the micrite envelopes of Bathurst, 1966) (Fig. 9c).

(5) Evidence for multiple phases of phosphate deposition includes the presence of several distinguishable cements within individual thin sections and the fact that the inner surfaces of some replaced molluscan shells carry phosphate growths which incorporate terrigenous detritus but pre-date the main sediment fill of the shell, itself cemented by a later generation of phosphate (OU 44315).

The paragenesis of Type 2-3 nodules is summarized in Table 1.

Table 1—Summary paragenesis for materials in the nodular phosphate layer, Waiau beech copse.



**Palaeontology.** (i) Ecology. Macrofossils are confined to two horizons. Within the Tunnel Burn Formation limestones *Lithothamnium-Lithophyllum* and *Amphistegina* are the dominant forms. In laterally equivalent sands, particularly in Section 2, fragments of large oysters and pectinids occur, probably *Pycnodonte* and *Athlopecten* respectively.

The nodular layer contains a moderately diverse fauna (D44/4; Table 2). The assemblage contains elements that suggest the presence of a hard bottom, notably the brachiopods and common turbinid gastropods. Other forms, such as *Athlopecten* and *Flabellum* were free-living epifauna, whilst the presence of *Venericardia* and other semi-infaunal or infaunal bivalves requires the presence of local patches of soft substrate. Apart from authigenic and diagenetic changes, most elements of the fauna are well preserved and some bivalves are represented by both valves, suggesting life assemblage conditions of preservation. The fauna is of shallow marine origin.

(ii) Age. The macrofossil assemblage of the nodular layer is facies restricted, but *Athlopecten* and the *Venericardia* are consistent with a mid-late Oligocene age (Ld-Lw), an age supported by the palynoflora in the base of the Point Burn Formation (D44/37; D. C. Mildenhall, pers. comm.).

The Garden Point Formation contains diverse planktic-rich foraminiferal assemblages of early Miocene age (Po-Pl; G. H. Scott, pers. comm.).

**Interpretation.** The early Kaikoura coal measure blanket apparently has only a thin and late development (Oligocene, Ld-Lw) on the eastern Fiordland margins, as found also in Central Otago. Fiordland and Central Otago presumably were emergent before the Oligocene, at which time a change in base level caused a phase of fluvial aggradation, followed rapidly by marine transgression in the west.

This marine transgression on basin margins was coeval with, or just post-dated, the development of flysch sedimentation in active fault-controlled basins along the Moonlight tectonic zone (Turnbull *et al.*, 1975; Norris *et al.*, 1978). During the Oligocene some 2-3 km of redeposited and hemiterigenous deep marine sediment accumulated at Blackmount (cf. Fig. 2), whilst only a few tens of metres of mainly shallow marine sediment accumulated nearby on the western (Fiordland) basin margin (cf. Fig. 5). The presence of a nodular phosphatic layer at the base of the Garden Point Formation, and of greensands and omission surfaces at corresponding stratigraphic levels in the Southland Plains sequence farther east (Hyden, 1979), is further evidence for slow Oligocene

Table 2—Faunal list for nodular phosphate layer, Waiau beech copse (D44/4).

|                                                                   |                                                         |
|-------------------------------------------------------------------|---------------------------------------------------------|
| Mollusca                                                          | Annelida                                                |
| <i>Cucullaea worthingtoni</i> Hutton                              | <i>Protula</i> sp.                                      |
| ? <i>Limopsis</i> sp.                                             | <i>Glomerula</i> sp.                                    |
| <i>Athlopecten athleta</i> (Zittel)                               |                                                         |
| <i>Lentipecten hochstetteri</i> (Zittel)                          | Coelenterata                                            |
| <i>Lima colorata</i> Hutton                                       | <i>Flabellum rubrum</i> Quoy and Gaimard                |
| <i>Venericardia</i> ( <i>Megacardita</i> ) <i>ponderosa</i> Suter | <i>Stephanocyathus mantelli</i> Milne Edwards and Haime |
| vererids (indet.)                                                 |                                                         |
| ? <i>Caryocorbula</i> sp.                                         | Rhodophyta                                              |
| <i>Perotrochus</i> sp.                                            | <i>Lithothamnium</i> sp.                                |
| <i>Margarella</i> sp.                                             | <i>Lithophyllum</i> sp.                                 |
| <i>Opella hendersoni</i> Marwick                                  | <i>Lithoporella</i> sp.                                 |
| <i>Turbo</i> ( <i>Modelia</i> ) sp.                               |                                                         |
| <i>Maoricolpus</i> sp.                                            | Brachiopoda                                             |
| <i>Hippionix</i> sp.                                              | <i>Terebratulina suessi</i>                             |
| <i>Xenophora neozelanica prognata</i> (Finlay)                    | <i>Tegulorhynchia squamosa</i> (Hutton)                 |
| <i>Notacirsa gracillimum</i> (Suter)                              | <i>Aetheia gualteri</i> (Morris)                        |
| <i>Willungia fracta</i> (Tomlin)                                  | <i>Waiparia elliptica</i> (Thomson)                     |
| <i>Proterato</i> sp.                                              |                                                         |
| naticoids (indet.)                                                |                                                         |
| ? <i>Austrotoma</i> sp.                                           |                                                         |
| <i>Dentalium solidum</i> Hutton                                   |                                                         |

sedimentation rates on the basin margins and is consistent with the existence of a regional Oligocene paraconformity (cf. Carter and Landis, 1972, and the appendix to this paper).

Detailed sedimentary interpretation of the nodular phosphate layer at the Waiau beech copse is difficult because of diagenetic effects, especially those associated with the dissolution of Tunnel Burn limestone at Section 4 to form the Type 1 nodules and their residual matrix. However, the fossils present in the nodular layer at Section 1 require the presence of areas of both hard and soft bottom on a shallow, current-swept sea floor, an interpretation supported by the petrographic evidence; at least at Section 1, the sea floor comprised a patchy "nodular phosphate" pavement closely similar to that inferred by Kennedy and Garrison (1975a) for Cenomanian sediments in southern England. In addition, local hardgrounds were probably present on top of the Tunnel Burn limestone (cf. Bromley, 1975; Fursich, 1979). The area was either cut off from a source of terrigenous detritus, or else the currents operative were sufficiently strong to cause bypassing of sediment.

During the early Miocene the sea floor on which the nodular phosphate condensed sequence had developed was swamped by an increasing influx of hemiterigenous mudstone (Garden Point Formation), and then by turbidites (Borland Burn Formation). What had been the Fiordland margin of the main Blackmount basin in Oligo-Miocene times sank much more deeply beneath the sea (cf. Fig. 2), suggesting either widening of the original graben by retrogressive step faulting along its margins, or possibly the development of new basins adjacent to the sites of the earlier depocentres.

### NORTHERN WEST COAST

Recent mapping, summarized in Nathan (1974), and detailed sedimentary investigation (Crooks and Carter, 1976), has provided much new information on the Kaikoura Sequence sediments of the West Coast. Nathan's nomenclature has proved controversial, and that of Crooks and Carter (1976) is preferred here.

The early Kaikoura history of the northern West Coast is similar to that of western Southland (Fig. 10). In the West Coast, however, the early Kaikoura coal measures are

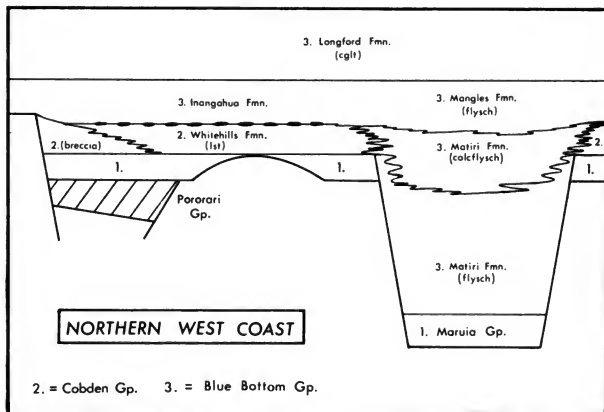


Fig. 10—Diagram of Kaikoura Sequence sedimentary units, northern West Coast.

associated with a marine transgressive sequence, the Maruia Group. In post-Eocene inferred basinal situations the Maruia Group is followed by thick sequences of deep water redeposited sediments, the lowest parts of the Blue Bottom Group (Crooks and Carter, 1976). In basin-margin situations the Oligocene sediments which correlate with the lower Blue Bottom are generally much thinner, often calcareous and locally include breccias and extremely shallow marine phases (Cobden Group; Crooks and Carter, 1976). These shallow marine phases are not part of the regional early Kaikoura marine transgressive cycle, but rather represent further and local flooding of the residual landmass caused by tectonism associated with Eo-Oligocene basin development and/or by global sea-level fluctuations (cf. Vail *et al.*, 1977).

At Whitecliffs, near Inangahua, Maruia Group sediments are overlain with low-angle unconformity by redeposited breccias and associated shallow marine beds of the Cobden Group (Whitecliffs Formation; Nathan, 1978a). A phosphatized and glauconitized nodular shellbed and hardground occur at the top of the Whitecliffs Formation, separating it from the deeper water calcareous mudstone and sandstone of the overlying Blue Bottom Group (Inangahua Formation; Nathan, 1978a).

Nathan (1978a) incorrectly recorded the Whitecliffs sequence as conformable throughout; in fact it contains two important unconformities, as further discussed below. Because of the accessibility of this locality it serves as an important standard of reference and has been studied in some detail by Lindqvist (1972). The sediments are exposed in the banks and slopes of the Buller River, a few kilometres northwest of Inangahua Junction, with the most informative outcrops occurring along the continuous western edge of Rosemount Ridge, immediately above and east of the main Inangahua to Westport highway (Fig. 11).

### Maruia Group

The relative thinness and the facies of the sediments developed at Whitecliffs (Fig. 12) suggest the locality was situated on a basin margin both during the Maruia Group



Fig. 11—Outcrop view of Whitecliffs locality, east bank of Buller River. Numbers refer to (1) breccia quarry; (2) unconformity between Kaiata and Whitecliffs Formation; (3) main outcrops of Whitecliffs Formation; (4) Inangahua Formation. Note: the conspicuous northward-dipping bedding plane between localities 3 and 4 is interpreted as due to large-scale scour and fill (cf. similar cross-beds in Fig. 15).

transgression, and during the later Cenozoic phases of tectonic and sedimentary activity. Though thick Brunner Formation coal measures are known nearby, as at Fletcher Creek and Burley's, at the base of the Whitecliffs section marine beds of the Island Formation rest directly on basement granite (grid reference S31/403612). In addition to well-sorted sandstones similar to those of the type locality of Island Formation, a muddy algal limestone lithofacies is well developed (the Courtney Member of Nathan, 1978a), as already reported from this horizon elsewhere (Gage, 1952; Webby, 1960). *In situ* bioherms of *Lithothamnium* up to 15 cm in diameter are set in muddy, quartz granule, foraminiferal matrix; there are closely associated glauconitic and foraminiferal limestones rich in *Asterigina* (Fig. 12). The Island Formation is followed gradationally by up to 120 m of dark mudstone of the Kaiata Formation with the characteristics described by Gage (1952) and Crooks and Carter (1976). The Kaiata Formation contains sparse macrofossils, including *Amalda* (*Baryspira*) *morgani* (Allan) (Phillips, 1963), and foraminifera confirm a late Eocene age (Ab-Ar; Nathan, 1973: 48).

### The lower unconformity and the Cobden Group

The Kaiata Formation is the highest unit of Maruia Group developed at Whitecliffs and is followed sharply by the Cobden Group sediments named the Whitecliffs Formation by Nathan (1974, 1978a). Two main lithofacies associations occur in the Whitecliffs Formation:

(i) Breccia lithofacies: Developed in the northeast at grid reference S31/384622 is a spectacularly angular and polymict breccia up to 30 m thick (Fig. 13). A thin basal granite conglomerate and cross-bedded calcareous sandstone rests in sharp unconformable contact on the underlying mudstone and passes rapidly up into the main breccia, which is composed of many varieties of both intrabasinal and exogenous clasts (Table 3) distributed along vague horizons in a matrix of spar-cemented quartzose and bioclastic sand. Some crudely graded beds occur in the breccia, but bed contacts are extremely diffuse, particularly in natural outcrops; clasts are often oriented with their long axes parallel to inferred bedding. A number of thin lensoid interbeds of micaceous, quartzose calcarenite occur. Boulder-sized clasts up to 30 cm diameter are common, more rarely attaining a size of 1.5 m or more. Amongst the smaller clasts and matrix, sutured and interpenetrating clast boundaries are common, presumably formed by pressure solution during compaction. Particularly significant amongst the intrabasinal clasts is the occurrence of boulders of pale grey marl similar to that of the Port Elizabeth Formation (Crooks and Carter, 1976); other clasts include coal and related Maruia Group lithologies.

(ii) Limestone lithofacies: Occurring overlying the breccia at grid reference S31/384622, and thence south along the cliffs to 370616 and beyond, is a sequence of

Table 3—Clast counts for all pebbles over 1 cm in maximum dimension on 4 x 1/4 m<sup>2</sup> bedding planes, breccia facies, Whitecliffs Formation.

| Pebbles over 1 cm diameter         |            |             |                         |
|------------------------------------|------------|-------------|-------------------------|
| Greywacke                          | 20         | 9           | } basement 86%          |
| Phyllite                           | 53         | 24          |                         |
| Hornfels                           | 70         | 32          |                         |
| Granite gneiss                     | 2          | <1          |                         |
| Diorite                            | 12         | 6           |                         |
| Vein quartz                        | 30         | 14          |                         |
| Mudstone (Kaiata)                  | 1          | <1          | } Kaikoura Sequence 13% |
| Marl (Port Elizabeth)              | 5          | 2           |                         |
| Sandy, algal limestone (Island)    | 11         | 5           |                         |
| Glauconitic or micaceous sandstone | 8          | 4           |                         |
| Glauconitic limestone              | 3          | 1           |                         |
| Coal                               | 1          | <1          |                         |
| Total                              | <u>216</u> | <u>100%</u> |                         |

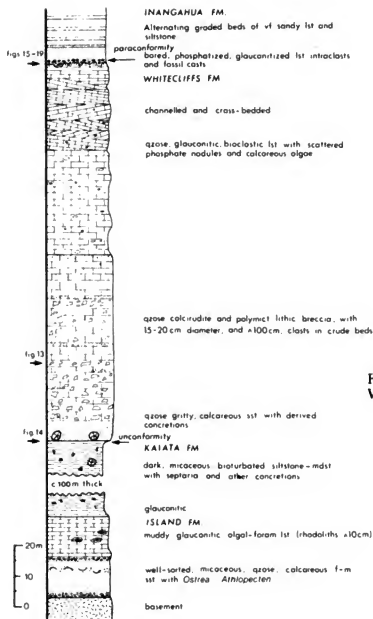


Fig. 12—Composite measured section, Whitecliffs area.

sandy, glauconitic, algal biosparites, showing interbedding of slightly coarser-grained (cemented) and finer-grained strata with conspicuous large-scale channelling and cross-stratification (cf. Fig. 15). Local horizons contain *Lithophyllum* rhodoliths up to 10 cm in diameter, and pink phosphatic nodules up to 4 cm in diameter, consisting of sand grains cemented by birefringent apatite, are common throughout the limestone. The upper parts of the limestone are finer grained and more massive.

The breccia lithofacies thins to the south, being represented in outcrops in the south-directed bend of the present Buller River channel by a fossiliferous quartzo-feldspathic grit with abundant intrabasinal mudstone and sandstone clasts, and large septarian concretions with a 5 cm thick rind of grit derived from the underlying Kaiata Formation. The contact with the Kaiata Formation is sharp and erosive and an unconformity is inferred (Fig. 14). Phillips (1963) reported a similar unconformity, but with a definite angular discordance of 10-15°, in road cuts at S31/383622; the upper surface of the Kaiata Formation was seen to be bored, and pieces had been incorporated in the base of the Cobden Group. This locality is now overgrown.)

#### The Whitecliffs-Inangahua contact (Figs. 15-18)

The contact between the Whitecliffs Formation and the overlying Inangahua Formation is similar to the contact between the Tunnel Burn and Garden Point

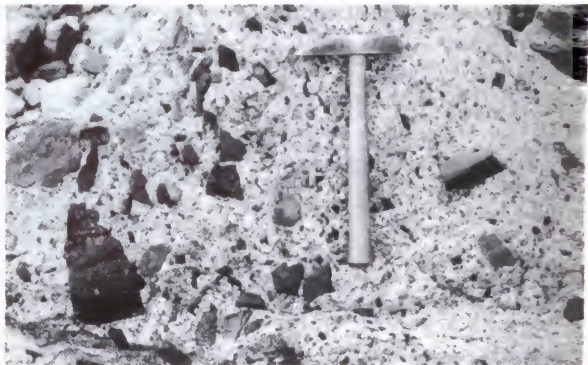


Fig. 13—Typical occurrence of breccia facies of Whitecliffs Formation.

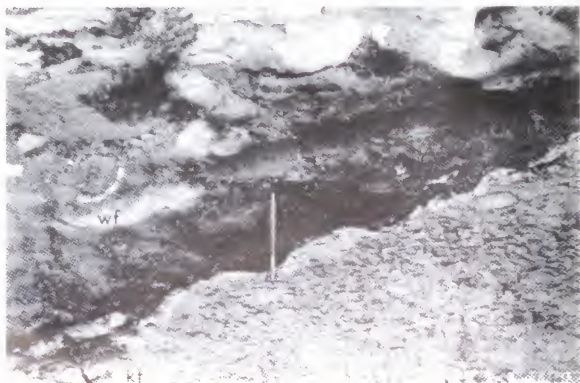


Fig. 14—Unconformable contact between the Whitecliffs (wf) and Kaiata (kf) formations (Locality 2, Fig. 11).



Fig. 15—Paraconformable contact (arrowed) between the Inangahua (if) and Whitecliffs (wf) formations (south of Locality 3, Fig. 11). Note: the contact can be traced around the hillside at a conspicuous break in slope at about 500 ft; it is incorrectly shown much higher on the ridge by Nathan (1978a).

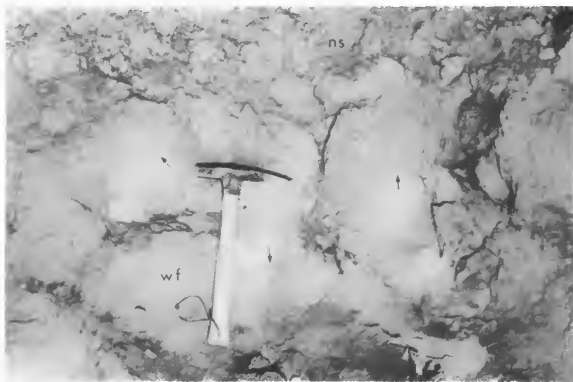


Fig. 16—Outcrop view of the burrowed top of the Whitecliffs Formation (wf), with nodular shellbed above (ns); thalassinidean burrows arrowed.





Fig. 17—Detail of nodular phosphate shellbed.

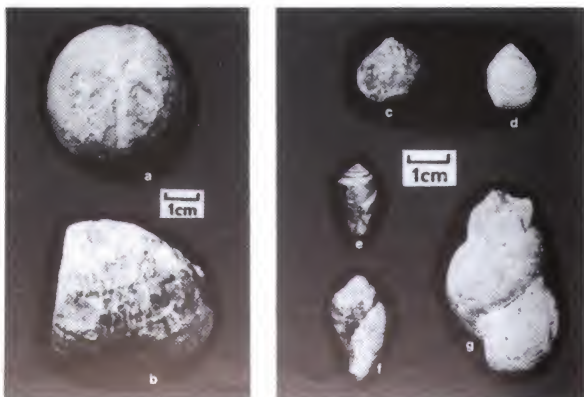


Fig. 18—Phosphatized moulds and steinkerns from the nodular shellbed: (a) *Opissaster*; (b) *Procardia*; (c) *Tegulorhynchia*; (d) *Liothyrella*; (e) *Conus*; (f) *Ficus*; (g) *Cymatiid gastropod*.

formations described earlier from western Southland, i.e., it is a paraconformable sequence. The Whitecliffs Formation has thalassinidean burrows penetrating down into it for up to 1.5 m which are filled with glauconitic and phosphatic sediment and fossils similar to those occurring in a nodular shellbed within the basal 20–30 cm of the Inangahua Formation (Fig. 16). The paraconformity occurs at a conspicuous break in slope, and can be traced for at least 200 m as a continuous feature.

The nodular layer consists of irregularly bored pebbles of fine sandy limestone, up to 20 cm in diameter and lithologically similar to that of the underlying Whitecliffs limestone, set in a matrix of phosphatized and glauconitized, quartzose, bioclastic, micritic grit (Fig. 17). Aragonitic fossils are preserved as phosphatized and/or glauconitized sediment-moulds, whereas calcitic brachiopods and echinoderms retain their shell, though it is usually replaced by phosphate and/or glauconite (Fig. 18). The limestone intraclasts reveal a complex sea-floor history with repeated episodes of boring and sediment fill (Fig. 19). Pebble surfaces generally have a pale-grey phosphatic skin enveloping an inner dark brown phosphate layer 1–2 mm thick; the dark phosphate commonly also lines the borings. A green glauconite stain penetrates up to 15 mm into the pebbles, some of which carry bryozoan or annelid encrustations. The sediment types in the borings include:

- (1) nodules of brown phosphatized limestone, themselves with a glauconitic surface;
- (2) several generations of shelly, phosphatic, creamy-brown micrite with included quartz pebbles; and
- (3) a less consolidated calcareous siltstone, rich in *Globigerina* and similar to that of the overlying basal Inangahua Formation.

### Petrography

**Terrigenous.** The clastic material in the Whitecliffs Formation comprises a variety of minerals and rock fragments derived from nearby basement lithologies, including fragments of the immediately older Maruia Group. The matrix of the breccia facies is markedly lithic, comprising poorly sorted grains of trachyte, phyllite, greywacke and

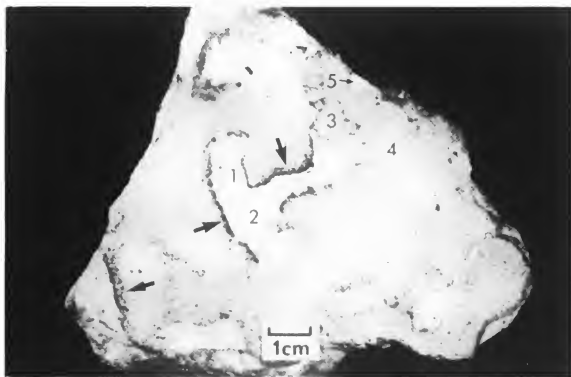
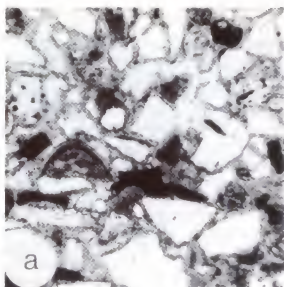
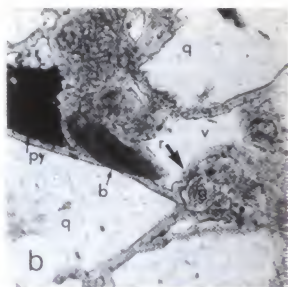


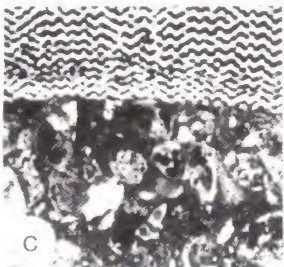
Fig. 19—Phosphatized limestone intraclast from the nodular shellbed. Note borings, with glauconite rims (arrowed), and at least five phases of sedimentary infill (numbered; 1–4 phosphatized).



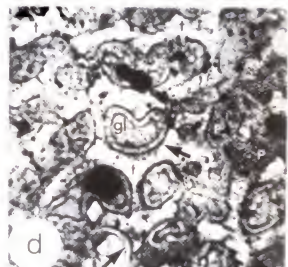
100  $\mu$



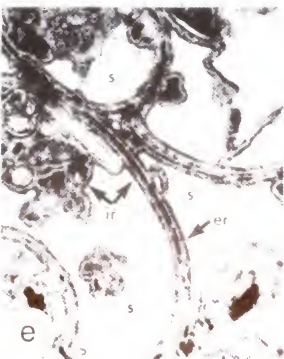
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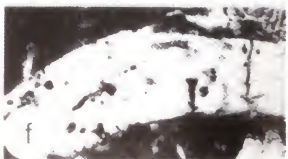
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hornfels together with potash feldspars, biotite and up to 10% quartz (OU 31319-20). Rock types whose identification was confirmed by thin section of pebbles included Greenland Group greywacke (OU 31313), a variety of hornfelses (OU 31315, 31317-18), biotite gneiss (OU 31309), granite (OU 31310, 31312) and trachyte (OU 31314).

**Bioclastic.** Calcareous phases of the Whitecliffs Formation contain a similar but reduced clastic mineral assemblage, being quartzose biosparites with scattered glauconite and pinkish-cream phosphate nodules. Bioclasts are dominated by algal fragments and mini-bioherms, usually *Lithophyllum*, and large benthic foraminifera, with lesser fragments of bryozoa, echinoderms, annelids and brachiopods. Many of the bioclasts carry algal borings. Sediment texture is packstone, with many grains in interpenetrating contact.

**Authigenic.** The petrography of the pebbles from the nodular layer at the Whitecliffs-Inangahua Formation contact is complex, with individual clasts and shells having been subjected to repeated cementation and authigenic alteration. The products always include phosphate, glauconite and pyrite, but otherwise vary widely throughout the nodular layer, with adjacent clasts having differing and complex parageneses. The following generalizations can nonetheless be made.

Except for authigenic alteration, the terrigenoclastic and bioclastic grains present in the clasts of the nodular layer are similar to those in the immediately underlying Whitecliffs Formation breccias and biosparites (OU 31322). Sand-sized clastic detritus is set in grainstone support in a brown, microcrystalline phosphate cement of low birefringence, which also contains scattered specks of more highly birefringent micritic or terrigenous dust (Fig. 20c). Bioclast preservation is exceptionally good for planktic forms such as *Globigerina*, which is generally abundant; benthic fossils are also well preserved, though they may be broken fragments or carry algal borings; benthic forms

Table 4—Summary paragenesis for materials in the nodular phosphate layer, Whitecliffs.

0. Original bioclast, sediment infilled
1. Shell replacement (phosphate and/or glauconite + pyrite)
2. Rim cementation (phosphate; rarely, scalenohedral calcite)
3. Boring on sea-floor (endolithic algae)
4. Main cementation of matrix (phosphate, rarely glauconite  $\pm$  pyrite) and infill of algal borings
5. Dissolution of remaining shell materials<sup>a</sup>
6. Void and empty chamber infill (glauconite  $\pm$  pyrite<sup>b</sup>; phosphate<sup>b</sup>; sparite<sup>c</sup> very rarely barite)
7. Recrystallization of any remaining unaltered shells (neomorphic inversion)

Notes: (a) accompanied or followed by compaction in some cases

(b) these chamber fills predate the main late stage sparite infill, and may have been deposited sometime during steps 1-4

(c) accompanied by fracturing of earlier cements, with some calcite veining.

Fig. 20 (opposite page)—Photomicrographs of phosphate nodules, Whitecliffs. Abbreviations as Fig. 8; additionally: b, biotite; *ir/er*, internal and external phosphate rim cements; t, calcite of echinoderm test; py, pyrite; v, void. (a) phosphate cemented terrigenoclasts and bioclasts in nodule (OU 31322); (b) detail of phosphate rim cement (OU 31322), (c) phosphate cemented sediment fill of irregular echinoid (OU 31331), test above; (d) detail of cement phases in echinoid stereom (OU 31331); phosphate rim cement (arrowed) followed by later phosphate or glauconite cement  $\pm$  pyrite; (e) foraminiferan with phosphate replaced test (dark) lined with internal and external rim cements; detrital grains inside test also phosphate rimmed; main chamber fill, sparry calcite (OU 31330); (f) phosphate-filled algal borings in recrystallized shell fragment (OU 31330); (g) shell fragment with scalenohedral calcite rim cement, set in main phosphate cement phase (OU 31330).

include rotaliid and textulariid foraminifera, and molluscan shell and echinoderm test fragments.

Bioclast shell and test replacements are common, and generally preceded the main phases of phosphate cementation. In incompletely altered fragments, replacement is by small granular crystals of phosphate, about 10  $\mu\text{m}$  in diameter, which coalesce to form a continuous zone of phosphate replacement around the outside of the bioclast (or along cracks or growth junctions within it), passing inwards to scattered granules within the shell calcite. In some cases phosphate replacement may be complete; for example, some foraminifera are preserved triple-layered, with a phosphate-replaced test between internal and external rim cements (Fig. 20e). In other cases shell fragments are replaced by microcrystalline glauconite and euhedral pyrite as well as or instead of phosphate. In such cases, replacement mirrors in details shell microstructures like crossed-lamellae and tubules (Fig. 21a).

Generally at least two discrete generations of phosphate cement are present:

(1) A rim cement of palisade form, up to about 40  $\mu\text{m}$  wide and comprising fibrous length-fast crystals with low birefringence; this early cement surrounds bioclasts, terrigenoclasts and glauconite crystals alike and also occurs occasionally as a lining within skeletal cavities, particularly echinoderm stereom (Fig. 20a-b, d-e); very rarely, a poorly developed scalenohedral rim cement of calcite is present instead of the phosphate rim cement (Fig. 20g);

(2) A later, inter- and intragranular, cavity-filling cement of random microcrystalline nature, which grew in botryoidal fashion, as shown by the shape of the arrested crystal front adjacent to drusy cavities in this cement.

X-ray diffraction analysis shows that all varieties of phosphate present are the carbonate fluorapatite francolite.

Replacement of the shell fragments and phosphate cementation was followed by the dissolution of the remaining original carbonate from most skeletal grains. In some cases collapse of the shell fragments then occurred, with apposition of their external and internal rim cements. In other nodules the cement was sufficiently strong to resist such compaction, and voids within shell fragments, and elsewhere, were filled with a coarse sparry calcite cement, in one case associated with barite (OU 31329). Very rarely, small voids remain within largely phosphate-replaced shell fragments, presumably because the voids were isolated from pore fluid access shortly after dissolution. The emplacement of void-filling sparite clearly post-dates the major phosphate cements, as its crystallization produced breakage of both the rim cement (Fig. 21b-c) and of fragments of the main intergranular cement (OU 31329). In at least one instance compaction, with consequent breakage of the rim cement, occurred before the deposition of the main sparite chamber fill (Fig. 21e).

Few shells escaped the various authigenic changes described above. Those that did include punctate brachiopods and some algal bored molluscan fragments (Fig. 20f); both are preserved as coarse calcite spar, with petrographic relations suggesting that there has been neomorphic replacement of the original shell material.

### **Paragenesis of the nodular layer**

Though different shells or nodules within the nodular phosphate layer may be replaced or cemented in different ways, there is an overall similarity of sequence of the major authigenic steps (Table 4). The general sequence is: bioclast replacement — rim cementation — matrix cementation — bioclast dissolution — void filling cementation.

The rarity of early carbonate rim cements, usually one of the initial phases of lithification of carbonate sediment, and the presence instead of a phosphate rim cement, both suggest early precipitation of this phosphate. Early cementation of nodules is also implied by the absence of syntaxial carbonate overgrowths on echinoderm fragments, and by the lack of compaction, with perfect preservation of the clastic grains, especially planktic foraminifera. Three lines of evidence suggest further that repeated episodes of phosphatization occurred, namely (1) partially phosphate-replaced shell fragments are penetrated by algal bores, themselves infilled with a later phosphate cement; (2) phosphate-cemented steinkerns and other shell-fills occur as clasts within the later

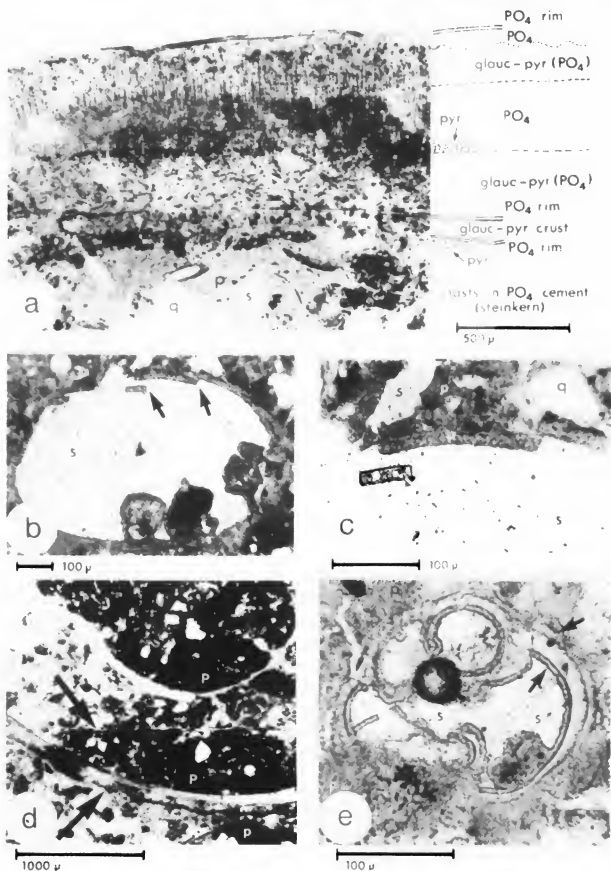


Fig. 21—Photomicrographs of molluscan phosphate nodule, Whitecliffs (OU 31330). Abbreviations as Fig. 8. (a) Complexly replaced molluscan shell fragment with phosphate rim cements, an internal glauconite-pyrite crust, and phosphate replaced and cemented steinkern (OU 31330); (b)-(c) phosphate-replaced foraminiferal test, fractured by compaction; sparite chamber fill; (d) phosphatized geopetal sediment fills inside phosphate rim-cemented (arrowed) bioclasts, themselves set in later phosphate cemented steinkern; (e) foraminiferan with internal and external rim cements (arrowed), fractured by compaction (bottom left) against phosphate-cemented echinoderm grain; test, neomorphic calcite; main chamber fill, sparite.

phosphatized sedimentary fill or other, larger shells (Fig. 21d); (3) nodules of phosphatized and glauconitized Whitecliffs limestone have peripheral borings and epifaunal encrustations, showing that the sea floor must have become sufficiently cemented for fragments to be broken off, and that such broken fragments then lay uncovered by sediment for an appreciable time.

It is concluded that phosphate rim cementation took place on or immediately beneath the sea floor, on top of a thalassinidean-burrowed surface on the Whitecliffs Formation (Fig. 16). The combined evidence suggests the development of a phosphate-cemented hardground, by a sequence of events similar to those inferred for Mesozoic hardgrounds in Europe (e.g. Bromley, 1975; Kennedy and Garrison, 1975b; Fursich, 1979). Further biotic activity, probably accompanied by bottom current erosion, resulted in the breakage of projecting parts of the hardground, with their incorporation as intraclasts within the nodular layer. Together with the accumulating shells and moulds of the contemporary biota, these intraclasts were then subjected to further authigenic alteration and cementation. Within the classification scheme proposed by Fursich (1979), the Whitecliffs occurrence corresponds to a Type 1 hardground, formed by Genetic Sequence 1.

### **Inangahua Formation and overlying beds**

The nodular layer grades rapidly up into interbedded very fine grained sandy limestones and marls of graded bed type, probably turbidites. Lower parts of the Inangahua Formation have bedding developed on a 10-30 cm scale, passing upwards into 40-140 cm thick beds with abundant *Zoophycus*. The formation is at least 300 m thick and passes up into a regressive sequence that culminates in the non-marine Rotokohu Formation (Lindqvist, 1972; Nathan, 1974, 1978a).

### **Palaeontology**

**Ecology.** The nodular horizon contains a rich and diverse fauna (Table 5), dominated by molluscs and echinoids. The assemblage is ecologically similar to that described from the similar horizon in western Southland. Hard and soft bottom forms occur in close association; many bivalves are present as double valves; and the fossils, apart from replacement, are well preserved. Epifaunal encrustations, notably bryozoans and annelid tubes, occur on the surfaces of some of the phosphate nodules. Most of the fauna is consistent with shelf water depths, but the absence of calcareous algae, abundant in the limestone below, may suggest appreciable depths on the outer shelf or upper slope.

**Age.** The various formations at Whitecliffs can be fairly well dated on combined macrofossil and microfossil determinations (Phillips, 1963; Lindqvist, 1972; Nathan, 1973, 1974). Maruia Group sediments are middle to late Eocene (Ar-Ak); the Cobden Group (Whitecliffs Formation) ranges from early to middle Oligocene (upper Lwh-Ld); and the basal Blue Bottom Group (Inangahua Formation) is late Oligocene to early Miocene (Lw-Po).

### **General interpretation**

The pattern of events indicated at Whitecliffs is closely similar to that already inferred for western Southland. Shallow marine transgression was sharply terminated in the Eo-Oligocene by a phase of faulting and basin formation. In places, as at Whitecliffs, tilting accompanied the faulting, resulting in minor angular unconformity between Maruia Group transgressive sediments and the Cobden Group breccias and limestones that overlie. This or a similar unconformity is best dated on the eastern side of the Murchison basin, at Owen River, where it is intra-Lwh (Kear, 1954).

After rapid erosion of the initial fault scarps, with the consequent formation of mass-transported breccias and conglomerates, the Cobden sea floor became impoverished in terrigenous detritus, and sediments are dominated by bioclastic or authigenic (phosphate, glauconite) phases. The sea floor was shallow (within the photic zone), and subjected to erosive current activity (large scale cross-bedding and channelling).

During the middle to late Oligocene (Ld-early Lw; Nathan, 1973, 1978b) a hardground developed along a burrowed and bored surface at the top of the Cobden Group calcarenites. The interpretation of this surface is similar to that already argued for the Tunnel Burn–Garden Point formation contact in western Southland. Happily, the Whitecliffs paraconformity has escaped severe diagenesis. As described above, the various stages in the development of a burrowed, diastemic, hardground surface are well displayed, and closely approach the idealized models of Kennedy and Garrison (1975b), Bromley (1975) and Fursich (1979).

Subsequent to the development of the hardground, in the latest Oligocene, the Whitecliffs locality started receiving hemiterigenous mudstone followed by turbiditic sediment, suggesting that renewed tectonic activity caused or followed the depression of the Whitecliffs area further beneath the sea.

## GENERAL DISCUSSION

### Hardgrounds and phosphatization

Many hardgrounds are produced by sea-floor or sub-sea-floor lithification by carbonate cements (e.g. Purser, 1969), as documented in modern seas by Shinn (1969). Later mineralization of the hardground surface by phases such as phosphate, manganese or glauconite is common, the mineralization usually being of sea-floor origin, and post-dating the main hardground cementation phase (Fursich, 1979; and references therein). One of the most thorough studies of mineralized hardgrounds is that of Kennedy and Garrison (1975b), who described glauconitized and phosphatized hardground surfaces from the English Chalk. These authors present compelling arguments for initial cementation of the hardgrounds by void-filling microspar and micrite, these carbonates later being replaced by phosphate and/or glauconite.

The evidence of original cementation of the Waiau and Whitecliffs hardgrounds is unfortunately poor, due to the overprint of later events. The actual hardground is not preserved at the Waiau beech copse, but indirect evidence, in particular the nature of the Type 1 nodules of residual origin, suggests that the hardground was cemented by early

Table 5—Faunal list from nodular phosphate shellbed, junction of Whitecliffs and Inangahua Formations (L29/29).

|                                                     |                                                           |
|-----------------------------------------------------|-----------------------------------------------------------|
| Mollusca                                            | Brachiopoda                                               |
| <i>Limopsis zealandica</i> (Hutton)                 | <i>Liothyrella concentrica</i> (Hutton)                   |
| <i>Parvamussium zitteli</i> (Hutton)                | <i>Campages</i> sp.                                       |
| <i>Limatula</i> cf. <i>trulla</i> (Marwick)         | <i>Terebratulina suessi</i> (Hutton)                      |
| ? <i>Hedecardium</i> sp.                            | <i>Tegulorhynchia squamosa</i> (Hutton)                   |
| <i>Longimactra leda</i> (Finlay)                    | <i>Waiparia</i> sp.                                       |
| ? <i>Teredo heaphi</i> (Zittel)                     |                                                           |
| <i>Procardia dolicha</i> (Suter)                    | Echinodermata                                             |
| ? <i>Cuspidaria</i> sp.                             | <i>Opissaster rotundatus</i> (Zittel)                     |
| <i>Astrea bicarinata</i> (Suter)                    | <i>Duncanaster</i> sp.                                    |
| <i>Maoricolpus</i> sp.                              |                                                           |
| <i>Pyræzus sutherlandi</i> (Marwick)                | Coelenterata                                              |
| <i>Serpulorbis ophioides</i> (Marshall and Murdoch) | <i>Flabellum pavoninum distinctum</i> (Edwards and Maine) |
| <i>Cirsotrema</i> sp.                               | <i>Stephanocyathus mantelli</i> (Edwards and Maine)       |
| <i>Capulus</i> sp.                                  |                                                           |
| <i>Cypraea trelissickensis</i> (Suter)              | <i>Keratisis</i> sp.                                      |
| <i>Willungia fracta</i> (Tomlin)                    | <i>Parisis</i> sp.                                        |
| <i>Magnatica</i> sp.                                |                                                           |
| <i>Polinices</i> sp. (Marwick)                      |                                                           |
| <i>Mayena sculpturatum</i> (Finlay)                 |                                                           |
| <i>Austrosassia procera</i> (Finlay)                |                                                           |
| <i>Ficus parvus</i> (Suter)                         |                                                           |
| ? <i>Austrofusius</i> sp.                           |                                                           |
| <i>Conus</i> sp.                                    |                                                           |
| <i>Aturia</i> sp.                                   |                                                           |



carbonate phases. The hardground at the top of the Whitecliffs Formation carries a mainly phosphate cement, in which occur scattered pools of coarse calcite spar. The petrographic relations are ambiguous, and either of two interpretations are possible: (1) initial cementation by carbonate, which was later largely replaced by phosphate (cf. Kennedy and Garrison, 1975b); or (2) initial cementation by phosphate, with later filling of any residual voids by sparry calcite. Though some of the sparite present is late stage void-fill type, some rather has the appearance of being a recrystallized early rim cement; this fact perhaps favours the first interpretation.

We conclude that the overall evidence suggests that both Waiau and Whitecliffs hardgrounds were produced by early carbonate cementation, and that mineralization of the Whitecliffs hardground was produced by later glauconite and phosphate replacement of the surface of the hardground. In contrast, the evidence is quite unambiguous that the phosphate nodules within the lag deposits above the hardgrounds *generally resulted from direct cementation by phosphate on and just below the sea floor*. Prior to cementation, many of the bioclastic components of the nodules were extensively bored by endolithic organisms and partly or wholly replaced by phosphate and/or glauconite and pyrite.

Our findings are in agreement with those of Lamboy (1979), who has stressed that there are two different ways in which sea-floor phosphate nodules may be formed. The available literature on modern nodules suggests that the first of these, the *replacement of calcium carbonate* by phosphate in shells on the sea floor, or in rock which has already been lithified, is commonest (e.g. D'Anglejean, 1968; Manheim *et al.*, 1975; Pasho, 1976; Birch, 1979). The second mechanism of nodule formation, by *direct phosphate cementation* of sediment on the sea floor, often within shell infills, is apparently less common. Lamboy (1979) and Parker (1975) have described modern cemented nodules of this type from off northern Spain, and similar ancient examples were recorded by Lowell (1952), Sheldon (1957), and Bushinski (1964).

We suspect that at least where phosphate nodules consist of phosphatized sediment moulds and steinkerns of fossil organisms, such as we have described from Whitecliffs and Waiau Beech Cope, their formation is in general due to direct phosphate cementation. Because of the geochemical mobility of phosphate, later recrystallization may often obscure the details of initial rim cementation, and lead to an incorrect interpretation of phosphatization as due to replacement of earlier intergranular carbonate cements or micrite (cf. Tourtelot and Cobban, 1968; Kennedy and Garrison, 1975a).

### Regional correlation and significance of Oligocene unconformities

There is more than superficial similarity between the early Kaikoura histories of western Southland and northern West Coast (Fig. 22). Provided the basinal nature of post-Eocene sedimentation is borne in mind, and allowance made for the complicated facies variations that may result, there is an almost one-to-one equivalence between the major sedimentary units, and hence the inferred tectonostratigraphic history, of the two areas. The only difference of substance is the presence in basin margin sequences in western Southland of only a single Oligocene hiatus. However, absence of an earlier, possibly angular, unconformity there might be due to (1) unfavourable outcrop (since there are few localities at which this part of the sequence is well exposed), or (2) only local development of the earlier unconformity as an easily recognizable feature; even on the West Coast it has only been recorded from a small number of basin-margin localities.

Carter and Norris (1976) have argued that the similarity between the Southland and West Coast areas is so great that they may have been part of a single sedimentary province that was only displaced along the Alpine Fault after the Oligocene. The evidence presented in this paper is consistent with such a view.

There are, however, convincing theoretical arguments as to why similarity of stratigraphy alone can never be a conclusive argument for the original contiguity of two sequences now located apart (cf. Voisey, 1958). In particular, Schofield (1960), in pre-plate tectonic recognition of some of the salient features of transform faults, has shown how "similar stratigraphical and volcanological patterns during geosynclinal sedimentation" may develop at opposing ends and sides of large transcurrent faults. With

| WESTERN SOUTHLAND |     |                         |                        | NORTHERN W. COAST |                                                 |                          |     |
|-------------------|-----|-------------------------|------------------------|-------------------|-------------------------------------------------|--------------------------|-----|
|                   |     | BASIN MARGINS           | AXIS                   | Tectonic Activity | AXIS                                            | MARGINS                  |     |
|                   |     |                         |                        |                   |                                                 |                          |     |
| MIOCENE           | Sc  |                         | conglomerate (Monowai) |                   | conglomerate (Longford)                         | coal measures (Rotokohu) | Sc  |
|                   | Pi  | flysch (Borland)        |                        |                   |                                                 | flysch, sst (Inangahua)  | Pi  |
|                   | Po  | mudstone (Garden Pt.)   | flysch (Borland)       |                   | flysch (Matiri-Mangles)                         |                          | Po  |
| OLIGOCENE         | Lw  | limestone (Tunnel Burn) | calciflysch (McIvor)   |                   | calciflysch (Matiri-C)                          | limestone (Whitecliffs)  | Lw  |
|                   | Ld  | sandstone (Point Burn)  |                        |                   |                                                 |                          | Ld  |
|                   |     | breccia                 | flysch (Blackmount)    |                   | flysch (Matiri-A,B)                             |                          |     |
|                   | Lwh | coal measures           | breccia                |                   |                                                 | breccia                  | Lwh |
|                   |     | or                      |                        |                   |                                                 |                          |     |
| EOC.              | Ar  | emergent                |                        |                   | coal measures and marine transgression (Maruia) |                          | Ar  |
|                   |     |                         |                        |                   | BASIN FORMATION                                 |                          |     |

Fig. 22—Comparison of the stratigraphic sequences of western Southland and northern West Coast (lithostratigraphic names in brackets).

the refinement of this concept into models of sedimentation in small active basins such as are currently believed to characterize continental transform boundaries (Wilcox *et al.*, 1973; Norris *et al.*, 1978; Reading, 1980), it is apparent that the stratigraphic similarities between Southland and the West Coast do not necessarily require original contiguity of the two areas, but might rather suggest their similar response to strike-slip tectonics within a complex zone of continental transform basins (cf. Carter and Norris, 1976; Norris *et al.*, 1978).

Refined stratigraphic documentation will be required for the resolution of these problems, but it is probably significant that both of the explanations discussed here, which are not necessarily mutually exclusive, require major mid-Cenozoic or younger transcurrent movements on the Alpine Fault.

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## Appendix: Oligocene unconformities in the South Island

R. M. Carter\* and C. A. Landis\*\*

Oligocene unconformities are widespread throughout New Zealand (Carter and Landis, 1972) and the southwest Pacific (Kennett *et al.*, 1974). The expression of these unconformities is often subtle, so that some investigators have failed to record their presence in carefully examined sections (e.g. Eade and Kennett, 1962). Ward and Lewis (1975) and Nathan (1978a) have even included sediments from above and below such unconformities in single formations, on the grounds of superficial lithological similarity. It is our experience that these unconformities are regionally significant, and that one or more Oligocene unconformity is present in all DSDP sites drilled in the New Zealand region (Kennett *et al.*, 1974), and in all known onland shallow marine sections (Carter and Landis, 1972; see also summary columns in Findlay, 1980), being unreported only in areas of Oligocene flysch sedimentation as in the Waiau and Murchison basins.

Carter and Landis (1972) proposed the name Marshall Paraconformity for a conspicuous and regionally widespread diastemic surface developed in the Canterbury Basin, along the east side of the South Island. Though broadly of middle Oligocene age, the paraconformity in the Canterbury basin is developed at the base of a sequence of greensands and limestones that are difficult to date precisely. In the light of the confusion displayed by later writers (Jenkins, 1975; Nathan, 1978b; Findlay, 1980), it is unfortunate that Carter assumed that the more precisely-dated unconformity at Owen River (Kear, 1954) was the single equivalent surface on the West Coast, and thereby wrongly inferred an early Oligocene (intra-Lwh) age for the Marshall Paraconformity at large.

The sequences described in this paper, particularly that from Whitecliffs, show that the development of the paraconformity in the Canterbury Basin may have overlapped in time with the development of at least *two* discrete unconformities on the West Coast: (1) a tectonic and locally angular discordance of early Oligocene age, as seen at Owen River, Whitecliffs and elsewhere; and (2) a genuine paraconformable condensed sequence of later Oligocene age, as seen at Whitecliffs and Waiau Beech Copse (western Southland).

### Type designation

To avoid further confusion, it is essential to define a name-bearer for the Marshall Paraconformity. There are many suitable sections in the Canterbury Basin, but that at Squires Farm, Pareora district, is designated as the type because of its central location within the on-land part of the basin and its distance from known contemporaneous volcanic centres (Fig. 1). *Hence the Marshall Paraconformity is here defined as the burrowed contact between the Squires Greensand and the Holme Station Limestone at the Squires Farm section (see Gair, 1963); the name is intended for the mid-late Oligocene hiatus or condensed sequences developed within the Canterbury Basin and elsewhere.* Micro-faunas indicate an early Oligocene (Lwh) age for the Holme Station Limestone, and a mid-late Oligocene (Ld) age for the Squires Greensand (Gair, 1963). As initially stipulated by Carter and Landis (1972), the term may usefully be extended to cover a thin condensed sequence in the absence of a single, unequivocal surface of hiatus. Indeed, the sequence of poorly terrigenoclastic greensand (Concord Greensand) and calcarenite (Weka Pass Limestone) developed above the actual paraconformity is itself often intensely

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bioturbated and, at least locally, as in the Hakataramea Valley, a further thalassinidean burrowed surface may occur at the top of the Weka Pass Formation.

### Dating

A major problem in correlation of the Marshall Paraconformity stems from the difficulty of dating its associated sediments accurately. Not only are facies often unfavourable, most of all so at the type localities for the upper two Oligocene microfossil zones of New Zealand (which therefore serve as most unsatisfactory standards of reference), but particularly on the West Coast there is also the problem of derived microfossils within the sediments above both unconformities (Lindqvist, 1972; Nathan, 1978b). However, taking the faunal evidence at face value, the Marshall Paraconformity in the Canterbury Basin encompasses parts of the early and middle Oligocene (Lwh-Ld zones), whilst its blanket of greensand-calcareenite ranges from mid to late Oligocene (Ld-Lw). On the West Coast, the lower, angular unconformity is of early Oligocene age (intra-Lwh), the associated Cobden breccias and limestones early to mid-Oligocene (upper Lwh-Ld), and the upper paraconformity mid to possibly late Oligocene (Ld-Lw). It remains possible, therefore, that the Marshall Paraconformity in the Canterbury Basin correlates with both the unconformities documented herein from the West Coast, consistent with Carter and Landis's (1972) suggestion that "locally the (Marshall) surface may 'bifurcate', or be represented by some thickness of pebbly lag deposit, rather than always lying at one precise horizon". However, the most striking similarities are those between the Marshall Paraconformity and the upper paraconformity at Whitecliffs and paraconformities at White Creek (Nathan, 1978b) and Waiau Beech Copse. Detailed studies of more sections, with particular attention to dating problems, might strengthen this correlation, and the corollary that both West Coast unconformities be treated as regionally distinct features in their own right.

### A REGIONAL SEDIMENTARY PIVOT

The presence of the Marshall Paraconformity and its blanket of greensand-calcareenite as the central pivot-zone within a regionally simple transgressive-regressive sequence had never received adequate explanation prior to Watkins and Kennett's (1971) prediction that widespread unconformities of this age should have formed as a consequence of inferred palaeo-oceanographic events. Particularly poorly explained before were the low content of terrigenous material, the marked faunal influx and the high energy (cf. Ward and Lewis, 1975), blanket-like nature of the greensand-calcareenite sediments by comparison with the low energy, terrigenous, transgressive-regressive nature of the sediments which lie above and below. Watkins and Kennett's interpretation, speculative then, is seen to be elegant and economical now; indeed, plausible alternatives are conspicuous by their absence.

Very many previously unexplained features of New Zealand's Oligocene-early Miocene sedimentary history are presently most profitably understood within the compass of the broad interpretation offered by Watkins and Kennett (1971), Carter and Landis (1972), Kennett *et al.* (1974), and Norris *et al.* (1978). In these authors' view, the end of early Kaikoura Sequence regional transgression resulted from tectonic events related to the breakthrough of the Antarctic-Australian mid-ocean ridge and its linkage with the southern end of the mid-Pacific rise (cf. Molnar *et al.*, 1976). With this linkage, and because of faster spreading rates between Australia-Antarctica than between New Zealand-Antarctica, the modern Indo-Australian-Pacific plate boundary started propagating through New Zealand, initially as a zone of rifting and depression in the west. This event is widely represented in western sedimentary sequences as an Eo-Oligocene change from transgressive to flysch basin types of sedimentation (Carter and Norris, 1976; Crooks and Carter, 1976), and is also marked in some basin-margin sequences (Whitecliffs, Owen River) by an angular unconformity. Meanwhile, and particularly outside of the tectonically affected western zone, the Marshall Paraconformity developed as a burrowed diastemic surface of regional extent that marked the end of the period of steady marine transgression that had accompanied New

Zealand's slow drift away from the Mid-Pacific Rise; a patchy blanket of greensand, preserved in the burrows and above, developed in the absence of terrigenoclastic input.

With the completion of rifting between Australia and Antarctica, strong bottom currents flowed across the New Zealand region, reworking the greensands developed on the Marshall Paraconformity and mixing and diluting them with both benthic and planktic bioclastic detritus to form the extensively cross-bedded Weka Pass and Cobden limestone facies. This phase of bioclastic sedimentation probably helped smooth any residual sea-floor relief on the margins of the western basins, which thereafter developed a non-depositional sedimentary regime, as represented by the nodular paraconformities at Whitecliffs and Waiau beech copse which are similar to but probably slightly younger than the main Marshall Paraconformity in the Canterbury Basin.

The regional development of the Marshall Paraconformity may have been accentuated by one or more contemporaneous sea-level adjustments (Vail *et al.*, 1977). Certainly, a sea-level fall would have exposed shallow shelf carbonate sediments to vadose cementation in the New Zealand region, to be followed by erosion during the ensuing sea-level rise. Such a eustatic cycle is therefore one way in which the Tunnel Burn and Cobden limestone intraclasts could have been produced and then concentrated into the late Oligocene nodular phosphate horizons.

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## Refinement of the side-by-side model for DNA

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Details of the refinement of the side-by-side (SBS) model for the B (moist fibre) form of duplex DNA are presented. Initial atomic co-ordinates were obtained from a  $2\text{ cm} = 1\text{ \AA}$  physical model by the theodolite measurements of atom positions. These were subsequently adjusted and refined to give bond lengths, bond angles and non-bonded intramolecular contacts within acceptable limits. Stereochemical features of the refined model are described and discussed in relation to a series of stereoscopic views of the model.

### INTRODUCTION

We have recently reported a set of atomic co-ordinates for a refined form of the side-by-side model for duplex DNA (Millane and Rodley, 1981). The objectives of this paper are to amplify the procedures used for obtaining the atomic co-ordinates and to describe in greater detail stereochemical features of the refined model. In particular we present details of a general method for obtaining atomic co-ordinates for a complex structure. This consists of theodolite measurement of a physical model and subsequent refinement of the initial co-ordinates using an appropriate computer program.

The SBS structure considered here (which applies to the solution or moist fibre B state of duplex DNA) is related to the Type I and Type II structures presented by Sasisekharan and Pattabiraman (1976) in the following manner. Both have alternating left-handed and right-handed, five-base-pair sections, but in Type II the left-handed nucleotide units are inverted with respect to their orientation in Type I. This produces a structure which has fewer close contacts in the bend regions. Indeed, from a study of space-filling models, Sasisekharan *et al.* (1978) subsequently concluded that while Type II was stereochemically acceptable, the Type I version produced unacceptable contacts between base and sugar atoms in the left-handed region. It is this Type I form which relates to the SBS model (Rodley *et al.*, 1976). However, when the Type I form was presented (Sasisekharan and Pattabiraman, 1976) no reference was made to a long-range twist feature specifically described for the SBS structure (Rodley *et al.*, 1976). It is unclear whether this was taken into account in the space filling stereochemical study of Type I (Sasisekharan *et al.*, 1978).

We consider that the long-range twist feature could be important for an understanding of the topological relationship of the duplex strands in *in vivo* covalently closed circular (CCC) DNA. Native CCC DNA is invariably supercoiled in a left-handed sense. This means that topological independence of the two strands (i.e. zero linking of the strands) could be achieved if the magnitudes of internal twisting and supercoiling are equal. This corresponds to  $\text{Tw} = -\text{Wr}$  and  $\text{Lk} = 0$  for the topological relationship  $\text{Lk} = \text{Tw} + \text{Wr}$  (where  $\text{Lk}$  is the linking number and  $\text{Tw}$  and  $\text{Wr}$  are the internal twisting and writhing (supercoiling) components respectively (see Crick, 1976)). Note that the Type II model is unlikely to produce an inherent long-range twist. The SBS structure, having more rigid bend conformations, becomes fixed into a right-handedly twisted arrangement.

In order to study the stereochemical viability of the SBS (Type I) model in greater detail it was necessary to construct a more accurate physical model than that originally

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used. This is described in the next section. Following sections deal with the measurement and adjustment of atomic co-ordinates obtained from this model. As we used theodolite measurements to obtain the initial co-ordinates we describe this procedure in some detail. This could be a convenient general method for obtaining accurate measurements of physical models of macromolecules. The initial co-ordinates were refined by adjusting atomic positions in the light of computed bond distance and bond angle values and close intramolecular non-bonded contacts. As discussed in Millane and Rodley (1981), we regard the limits chosen for these parameters ( $\pm 0.025$  Å for bond lengths,  $\pm 2.0^\circ$  for bond angles and a minimum distance of 2.75 Å for non-bonded contacts) to be reasonable in relation to known data and expectations for polymeric structures. Finally we discuss features of the refined model as they relate to known physical data for duplex DNA and related structures.

## CONSTRUCTION OF THE PHYSICAL MODEL

A physical model was constructed using Kendrew ( $2 \text{ cm} = 1 \text{ Å}$ ) molecular units for the sugar phosphate backbone and perspex plates to simulate the base pairs. The latter had holes drilled at appropriate positions and angles for the insertion of metal connecting rods for C1'-N glycosidic bonds (Fig. 1). The perspex plates were held by horizontal metal rods attached to a stand. These rods could be twisted or tilted (about position A, Fig. 1) to give as much flexibility as possible in the positioning of the perspex plates.

The Kendrew units were altered to give bond lengths and bond angles as close as possible to standard values (Arnott, 1970; Arnott and Hukins, 1972) before assembling them together. The construction of Kendrew units is such that torsional angles may be varied without difficulty. Using these degrees of freedom and those of the perspex plates a physical model was constructed for a seven-base-pair unit. The spacing between the perspex plates was kept at 3.4 Å as far as possible. The sugar puckers were not held constant as in double-helical models, although the C3*endo* conformation was chosen as the starting pucker for all of the sugars except the A9 one. (C3*endo* is probably the best form for left-handed sections.) Thus varying degrees of puckering were allowed. The basic arrangement chosen was that of the initial model (Rodley *et al.*, 1976). Some alternative arrangements, in particular at the bend regions, were explored, but the only change made was to the backbone conformation at A8 (and B3) which was changed from *tg* to *gt*. Seven base pairs were used in order to facilitate the identification of the two two-fold axes of symmetry that were assigned to the SBS model in order for a continuous

Table 1—Gross features of model<sup>a</sup>

|                              | 3'  |    | 5'  |                              |
|------------------------------|-----|----|-----|------------------------------|
| C3 <i>endo</i>               | A5  |    | B5  | C3 <i>endo</i> <sup>gt</sup> |
| <sup>gt</sup> C3 <i>endo</i> |     | L2 |     | <sup>gt</sup> C3 <i>endo</i> |
| <sup>gt</sup> C3 <i>endo</i> | A6  |    | B6  | C3 <i>endo</i> <sup>gt</sup> |
| <sup>gt</sup> C3 <i>endo</i> | A7  |    | B7  | C3 <i>endo</i> <sup>gt</sup> |
| <sup>gt</sup> C3 <i>endo</i> | A8  |    | B8  | C3 <i>endo</i> <sup>gt</sup> |
| <sup>gt</sup> C3 <i>exo</i>  | A9  |    | B9  | C3 <i>endo</i> <sup>gg</sup> |
| <sup>gg</sup> C3 <i>endo</i> | A10 |    | B10 | C2 <i>endo</i> <sup>gg</sup> |
| <sup>gg</sup> C2 <i>endo</i> |     | R2 |     | C3 <i>endo</i> <sup>gg</sup> |
| <sup>gg</sup>                | A11 |    | B11 | C3 <i>endo</i>               |
|                              | 5'  |    | 3'  |                              |

<sup>a</sup> Labelling of bases corresponds to that used by Rodley *et al.*, 1976. The asymmetric unit is boxed. L<sub>2</sub> and R<sub>2</sub> are two-fold axes located at the centres of five base pair left-handed and right-handed regions respectively — the sense of helical twist of the structure alters from left to right at the A8-B8 base pair, producing bend regions, p (at B8) and q (at A8).

duplex to be constructed from the five-base-pair asymmetric unit. The overall arrangement in terms of gross features is summarised in Table 1. It was only in the subsequent refinement that it was found necessary to change the conformation of the B10 (and A1) sugar from C3*endo* to C2*endo*.

Non-bonded contacts were assessed and minimised throughout the construction of the model. Because of the size of the molecular unit and the relatively high number of degrees of freedom it possesses there are limitations in determining the most favourable conformation. It is necessary to have a comparatively rigid physical model but also one for which small changes over several atoms (e.g. in the change of sugar puckering, which affects polynucleotide conformations very significantly) can be readily made. The Kendrew units are reasonably satisfactory for these purposes. An ability to move the bases (of pairs) independently of each other would have given more flexibility in constructing the model. This was done to some extent in the refinement when base atom co-ordinates were introduced, as outlined below. The mounting arrangement for the perspex plates did allow the perspex base pair to be moved quite readily. This was an important factor as it was found necessary to vary their positions significantly from those in the initial model where the base pairs had been constrained to lie directly above each other as far as possible.

### MEASUREMENT OF CO-ORDINATES FROM THE PHYSICAL MODEL

The method adopted for the measurement of atomic positions involved the use of a pair of theodolites (Sokkisha, model T60D having automatic vertical index and upright image). These were located in a triangular manner, with respect to the model, as shown in Figures 1 and 2. The two theodolites were set at the same horizontal height and the distance between them measured accurately ( $d = 2249$  mm). Sightings of each atom were made with each theodolite. Each sighting provides two angular values; a horizontal one ( $\theta$ ) and a vertical one ( $\alpha$ ). As the distance between the two theodolites was known, positional ( $x, y, z$ ) co-ordinates for each atom could be determined directly from three of the theodolite angles e.g. ( $\theta_1, \theta_2$  and  $\alpha_1$ ), where, as indicated in Figure 2,  $\theta_1$  and  $\theta_2$  are the horizontal readings from the two theodolites, 1 and 2, and  $\alpha_1$  is the vertical reading from theodolite 1, using the relationships

$$x = \frac{\tan \theta_2 d}{\tan \theta_1 + \tan \theta_2}$$

$$y = x \tan \theta_1$$

$$z = \frac{x}{\cos \theta_1} \tan \alpha_1$$

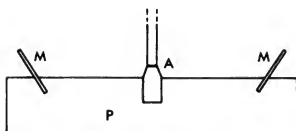


Fig. 1—Details of base pair section of physical model (A = mounting rod; P = perspex plate; M = metal connecting rod for Cl'-N glycosidic bond).

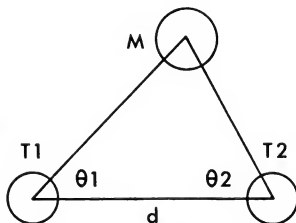


Fig. 2—Geometrical arrangement of theodolites and physical model (M = model; T1, T2 = theodolites 1 and 2).

The model was positioned so that there would be minimum eclipsing of one atom by another. We did not find it necessary to use a second setting of the model with respect to the fixed theodolite positions. Positions of atoms which could not be viewed directly could be readily estimated if the atoms were pointed to from different angles by an assistant. Theodolite angles could be measured to  $\pm 0.5^\circ$ . This gives an accuracy for the measurements of the order of  $\pm 0.002$  Å for each axis which is well within the bond length accuracy of  $\pm 0.025$  Å for the physical model. The limiting factor in obtaining co-ordinates was therefore that of building the physical model sufficiently accurately. Ideally one should use a larger scale physical model than a  $2\text{ cm} = 1\text{ Å}$  one in order to enable the model to be built more accurately. We regard the theodolite method to be a very convenient and rapid one for obtaining co-ordinates from a physical molecular model.

## REFINEMENT OF THE INITIAL CO-ORDINATES

In order to refine the atomic co-ordinates obtained from the model to within the stereochemical constraints described in the introduction, a program was written to perform the following operations on the measured co-ordinates:

1. Transformation of co-ordinates from the theodolite co-ordinate system to a co-ordinate system (in Å) in which the  $L_2$  two-fold axis (Table 1) coincides with the y-axis and the  $R_2$  axis (Table 1) lies in the x-y plane and intersects the z-axis.
2. Calculation of the co-ordinates of the terminal oxygen atoms O2 and O3 so that the bond lengths and angles of these atoms to the phosphorus atoms are equal to the standard values (1.48 Å and  $116^\circ$ ).
3. Calculation of bond lengths, bond angles and short non-bonded interatomic distances within the asymmetric unit.
4. Generation of atomic co-ordinates for nucleotides 5 and 11 by rotation about  $L_2$  and  $R_2$ .
5. Calculation of bond lengths and bond angles about the O1-C3 bond across the two-fold axes and short non-bonded contacts between the asymmetric unit and nucleotides 5 and 11.
6. Calculation of the distances of C2 and C3 from the C1-O5-C4 plane for each sugar ring to provide a quantitative measure of the sugar puckers.
7. Calculation of the N-N distance for each base pair, the N-N-Cl angle for each base and the tilt angle (see 8 below) between the glycosidic (N-Cl) bonds.
8. Positioning of the bases on the glycosidic bonds and making provision for individual bases to be rotated perpendicular to (referred to here as "tilt") and about ("twist") the glycosidic bond.
9. Calculation of hydrogen bond lengths, dihedral angles (angle between the two base planes of a pair) and base-base and base-backbone short non-bonded contacts.

This program was used as the basis for the refinement procedure. There were three objectives to the refinement which overlapped to a considerable extent: (a) to bring the bond lengths, bond angles, non-bonded distances and sugar puckers within the required limits, (b) to obtain the positions of the two fold axes  $L_2$  and  $R_2$  to ensure connectivity throughout the molecule with the same stereochemical constraints and (c) to position the base groups within the sugar-phosphate backbone so as to satisfy the same constraints on non-bonded contacts and align the bases within a pair as well as possible. These objectives were achieved by carrying out the refinement procedure in the following steps:

1. The co-ordinates were adjusted until the bond lengths, bond angles, and non-bonded distances were within the required limits (see first section) and acceptable sugar conformations were obtained (Table 4, Millane and Rodley, 1981).
2. In order for the backbone to accommodate the base pairs as well as possible, the two strands were shifted relative to each other to make the N-N distances as close as possible to the standard value for the base pairs. Individual backbone atoms were also adjusted to bring the N-N distances and N-N-Cl angles as close as possible to standard values and to minimise the tilt angle between the glycosidic bonds.

3. The two-fold axis  $L_2$  was initially estimated as being the line joining the midpoints of A5N-B6N and B5N-A6N (and similarly for  $R_2$ ) where the co-ordinates of nucleotide 5 and 11 were obtained from the model.

4. Using these two-fold axes, atomic co-ordinates were generated (from the asymmetric unit) for nucleotides 5 and 11. The stereochemistry across the two-fold axes was adjusted by determining correct relative positions of the linking atoms O1 and C3 and deriving new two-fold axes. This step was repeated until the stereochemistry across the two-fold axes was within the required limits.

5. Each of the four bases (A, T, G or C) was inserted in each nucleotide and the position of the glycosidic nitrogen atom adjusted to minimise contacts to the backbone and improve the hydrogen bond lengths.

6. The bases were then "tilted" to minimise the remaining non-bonded contacts and the dihedral angle between the bases. This was followed by a small amount of twisting to make the two bases of a pair as coplanar as possible.

### DETAILS OF THE REFINED MODEL

The resulting backbone structure has bond lengths and bond angles within 0.025 Å and 2.0° of standard values. Non-bonded distances are greater than 2.75 Å (2.90 Å for C-C distances). Two-fold axes were obtained which maintain these stereochemical limits throughout the molecule. For  $L_2$  this proved to be reasonably straightforward, as the conformations of successive base pairs in the left-handed region are practically identical. For the right-handed region, by contrast, the C3<sub>exo</sub> conformation at A9, that is related to the bend geometry, influences the geometry about  $R_2$  in a more asymmetrical manner. Thus greater difficulty was encountered in establishing connectivity about the  $R_2$  position. It was found necessary to alter the sugar pucker at B10 from C3<sub>endo</sub> to C2<sub>endo</sub> in order to obtain a stereochemically acceptable two-fold axis of symmetry between nucleotides 10 and 11. Base-pair hydrogen bond lengths are close to the standard values. More details on these parameters are given in Millane and Rodley (1981).

The base groups were fitted into the backbone structure successfully, although a number of C-C non-bonded distances are between 2.80 Å and 2.90 Å. Base tilt angles (between the glycosidic bond and the base plane) are listed in Table 2. These are less than the maximum value of 11° observed by Haschemeyer and Rich (1967). Base twist angles were small, all being less than 1°. The dihedral angles between bases of a pair, also listed in Table 2, are all less than 4°. Details of the standard values used for bond distances and bond angles, and a quantitative discussion of sugar puckers and close contacts are given in Millane and Rodley (1981) which also contains a full listing of the atomic co-ordinates.

Stereoscopic diagrams obtained from the atomic co-ordinates are presented in Figures 3-10 in order to highlight various features of the refined model.

Table 2—Base-pair geometry

| Base | Tilt (°)      | Dihedral (°) |
|------|---------------|--------------|
| A6   | -2.1          | 0.3          |
| A7   | 0             | 2.7          |
| A8   | 0             | 1.1          |
| A9   | -0.5 to 5.0   | 0.1          |
| A10  | 0             | 1.2          |
| B6   | 0             |              |
| B7   | 5.0           |              |
| B8   | 5.6           |              |
| B9   | -3.9 to -10.4 |              |
| B10  | 6.0           |              |

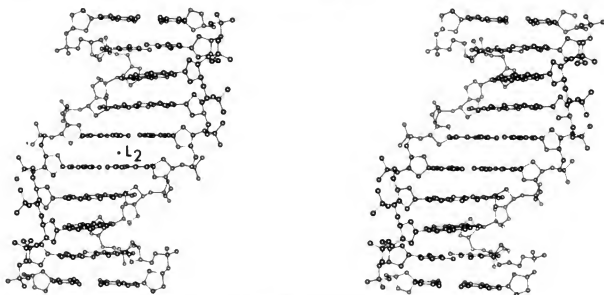


Fig. 3—Stereoscopic view along  $L_2$  with left-handed region in centre.

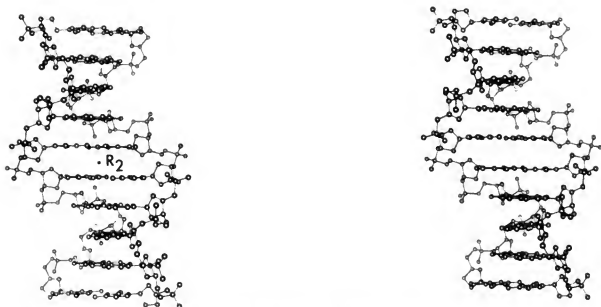


Fig. 4—Stereoscopic view along  $R_2$ , with right-handed region in centre.

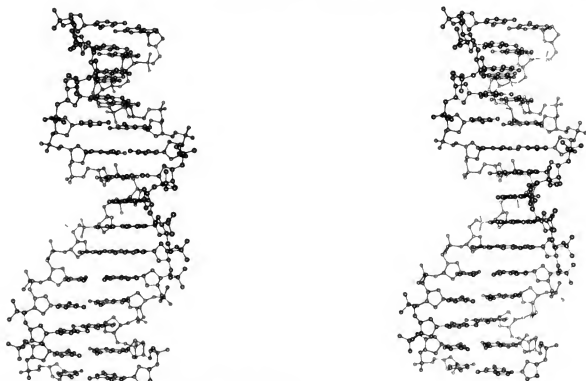


Fig. 5—Stereoscopic view of 15 base pair section.

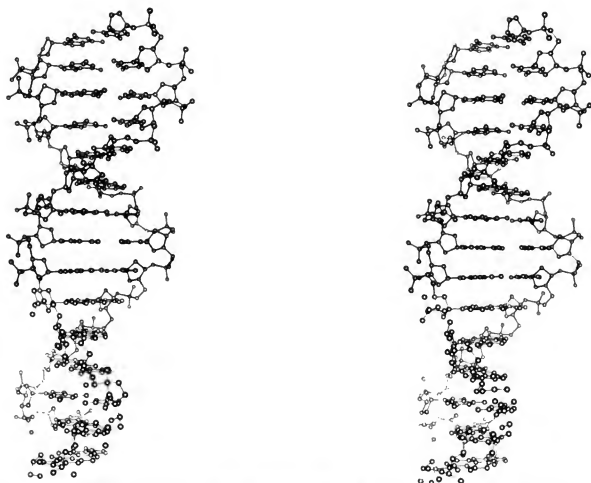


Fig. 6—Stereoscopic view of 15 base pair section rotated 90° with respect to that in Figure 5.

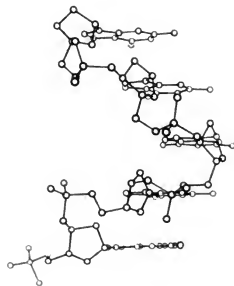
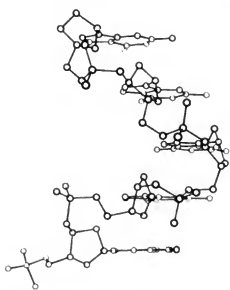


Fig. 7—Stereoscopic view of sharp (q) bend region.

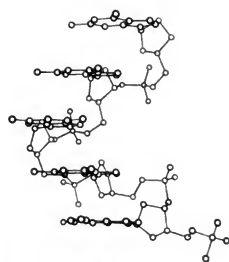
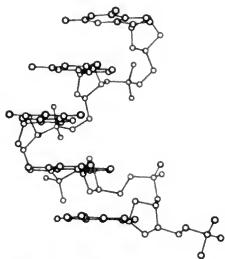


Fig. 8—Stereoscopic view of sharp (q) bend region rotated 180° from that of Figure 7.

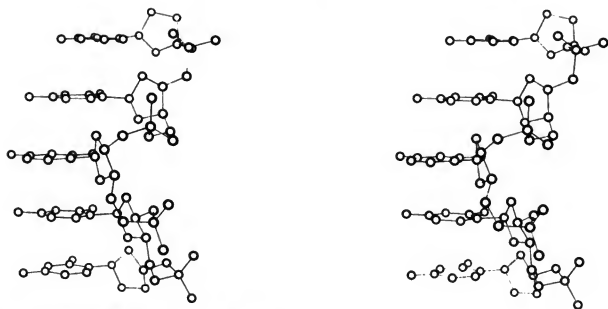


Fig. 9—Stereoscopic view of p bend region.

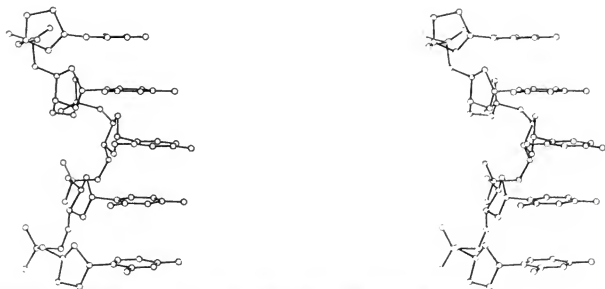


Fig. 10—Stereoscopic view of p bend region rotated 180° from that of Figure 9.



Figures 3 and 4 give views of separate ten-base-pair units viewed along the  $L_2$  and  $R_2$  two-fold axes respectively ( $R_2$  is rotated  $23.4^\circ$  anticlockwise, about the molecular axis, from  $L_2$ ). Figure 3 has the left-handed section in the centre while Figure 4 presents a view of the right-handed region. Figures 5 and 6 give two views of a single fifteen-base-pair unit. In Figure 5 the upper section corresponds to the Figure 4, right-handed region. Figure 6 is rotated  $90^\circ$  clockwise with respect to Figure 5.

Details of the left-handed region (Figs. 3, 5 and 6) are of interest in relation to the claim by Sasisekharan *et al.* (1978) that this region presents stereochemical difficulties. The stereoscopic pictures and interatomic distances show that this region is free of close non-bonded contacts. However the SBS structure is probably more skewed than that considered by Sasisekharan *et al.* (1978). The structure must adopt a skewed ladder conformation rather than a helical one for the particular sugar and backbone arrangements chosen. If extended this left-handed structure would produce a helix of rather large diameter and large repeat, unlike that of the more compact left-handed Z form of poly dG.dC (Wang *et al.*, 1979). A SBS interpretation of the high salt - low salt transformation for poly dG.dC that involves an inversion of optical rotation (Pohl and Jovin, 1972) could envisage the change of either left-handed or right-handed regions into the left-handed Z conformation. The latter possibility would effectively correspond to the double helix explanation. In the former case an increase in left-handedness would arise from the transformation of the less helical left-handed SBS to the more helical Z form. Either SBS approach would result in a change of the long-range twisting from a right- to a left-handed sense, thereby altering the sense of the optical rotation, as observed (Pohl and Jovin, 1972).

For the right-handed section (Figs. 3, 4, 5 and 6) there are the following  $<2.90 \text{ \AA}$  carbon-carbon contacts between the sugar rings and the bases: C8-A10C2 =  $2.81 \text{ \AA}$  C6-B8C2 =  $2.81 \text{ \AA}$  C6-B9C2 =  $2.80 \text{ \AA}$  and C6-B5C2 =  $2.86 \text{ \AA}$ . It is quite possible that these contacts could be reduced significantly by further adjustments of the model. Difficulties arose as a result of not constructing the right-handed A10-B10 to A11-B11 region sufficiently precisely before theodolite measurement, and this caused problems in determining  $R_2$ . Ideally, overall adjustment of the initial physical model should also be considered after a refinement procedure of the type adopted here. However these contacts are still within the "rare" limit of Haschemeyer and Rich (1967). Further tilting and twisting of the bases could have been invoked. Levitt, for example, used a very much higher degree of tilting in his model for B-DNA (Levitt, 1978).

A comparison of Figures 3 and 4 shows the greater compactness of the right-handed region which results from the greater ease of twisting a helical structure in that direction for duplexes having the D rather than L sugar conformation.

Details of the bend regions (p and q, Table 1) are given in Figs 7-10. Close contacts between non-bonded atoms which tend to fix these into reasonably rigid conformations are as follows:

| p bend                         | q bend                         |
|--------------------------------|--------------------------------|
| B9O4-B8C2 = $2.75 \text{ \AA}$ | A8O4-A9C1 = $2.75 \text{ \AA}$ |
| B9O4-B8C3 = $2.76 \text{ \AA}$ | A8O5-A8O2 = $2.87 \text{ \AA}$ |
| B9O4-B8C4 = $2.84 \text{ \AA}$ | A8O3-A9C4 = $2.75 \text{ \AA}$ |
|                                | A8O3-A9O5 = $2.88 \text{ \AA}$ |

We consider that these values do not indicate that excessive strain exists within the bend regions and that the results for the refined model show the viability of bending a duplex structure in this manner.

An important feature of the refined model is its connectivity between successive asymmetric units. This is illustrated in Figures 5 and 6 which contain three such units. From these figures the effect of the long-range twisting ( $46.8^\circ/10$  base pair unit or  $23.4^\circ$  between  $L_2$  and  $R_2$ ) can also be seen. We consider this value may have been overestimated because (1) the right-handed region can possibly be constructed with a lower degree of right-handed twisting and (2) the present structure is probably, overall, too rigid especially with regard to base conformation. Any adjustment of the structure that took these into account would lead to smaller net twisting.

## CONCLUSION

Analysis of a SBS structure differs markedly from that of double helical models. The latter may be refined directly using standard least-squares techniques (Arnott and Hukins, 1973) because, since all nucleotides are equivalent, there is only a small number of variable parameters in the molecule. However, for the SBS structure each nucleotide in the asymmetric unit may have a different conformation, the variability of the pucker configuration of the ten sugar rings being the most important factor. In addition the torsional angles for the backbone may be varied from one nucleotide to the next and base positioning is also more variable than in a double helix. Using a starting physical model has the advantage, for a complex structure such as this, of establishing a plausible initial arrangement, which may then be refined in the manner described here. It is likely that an analysis similar to this one could be made using a starting model having somewhat different gross features. Thus we do not claim to have identified the arrangement of minimum strain energy, and the long-range twist effect may have been overestimated. Nonetheless, the overall features presented here may be regarded as a reliable description of the SBS structural possibility for duplex DNA.

## ACKNOWLEDGEMENTS

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## The status of the genus *Reflectopallium* Burton (Gastropoda: Athoracophoridae)

D. W. Burton\*

The status of the genus *Reflectopallium* is examined. *Reflectopallium papillatum* is reduced to synonymy with *R. pseudophyllum*, the type species, and the genus is reduced to synonymy with *Pseudaneitea* Cockerell, 1891. A full description of *P. pseudophylla* is given.

### INTRODUCTION

The genus *Reflectopallium* was erected by Burton (1963) and included four species, three of them new. These were *R. pseudophyllum*, the type species, from Hawdon River, mid-Canterbury, *R. papillatum*, from Mt Algidus, and *R. delli* Central Trio Is., Pelorus Sound. The remaining species, *R. martensi*, was a rather aberrant athoracophorid from the Auckland Islands, originally included in the genus *Pseudaneitea* Cockerell, 1891.

The main diagnostic feature of the genus was the shape of the posterior margin of the mantle area, which was described as "running diagonally forwards before recurving to run back to the perinotum" (Burton, 1963). Some doubt was cast on the reliability of this feature by Barker (1978), who found in his study of *Athoracophorus bitentaculatus* a number of specimens in which the posterior margin of the mantle area recurved in exactly the same way as that described for *Reflectopallium*. He thereupon suggested that *Reflectopallium* be synonymised with *Athoracophorus*. However, the species now included in *Reflectopallium* are markedly different in skin texture, habitat, and overall shape from those in *Athoracophorus*, and, as has already been pointed out (Burton, 1980) merging these two genera would be an unsatisfactory solution.

In an attempt to resolve this situation, further collecting was carried out during April, 1978, and January, 1981, and nine more specimens of *R. pseudophyllum* were found. After examination of these specimens and of the existing type material, it is now possible to resolve the problem.

### MATERIALS AND METHODS

Slugs were relaxed and killed by drowning and preserved in 5% formalin.

#### Jaw and radula

After dissecting the jaw from its anterior aspect, the buccal mass was boiled in a strong solution of caustic soda to macerate the soft tissues. The intact radula was washed in water, stained in 2% aqueous aniline blue for 2 minutes, destained for 10 minutes in lactic acid, transferred to xylol, gently unrolled in a drop of DePeX on a microscope slide, and covered with a coverslip. Radula teeth were drawn using a Zeiss camera lucida.

#### Pallial system

The anatomy of the pallial system was determined by serial sectioning. As no shell spicules were observed, decalcification prior to sectioning was not necessary. The material was embedded in 56°C M.P. wax, serially sectioned at 20 µm, and stained with Masson's Trichrome stain. A composite view of the pallial system was then built up.

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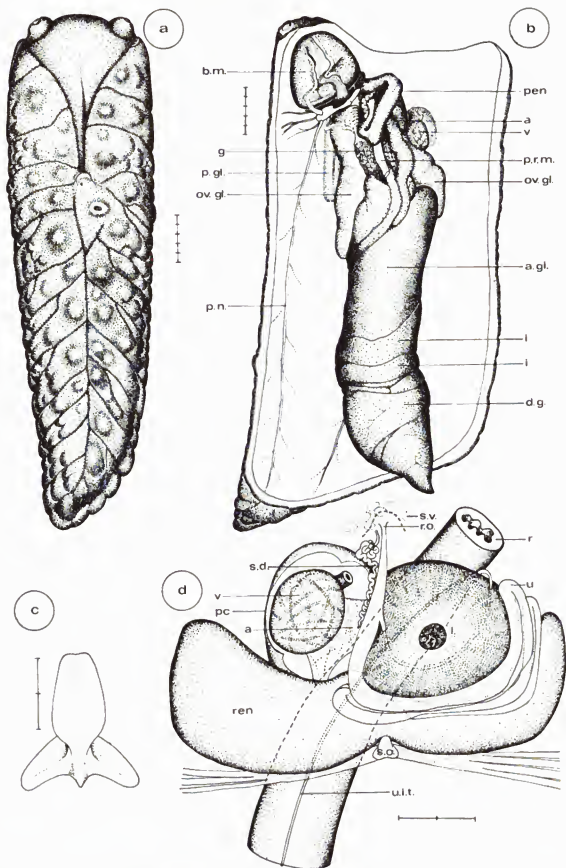


Fig. 1—(a-d) *Pseudaneitea pseudophylla*: (a) externals; (b) viscera *in situ*; (c) jaw; (d) pallial system, reconstructed from serial sections. a. — atrium; a.gl. — albumen gland; b.m. — buccal mass; d.g. — digestive gland; g. — gonad; h.d. — hermaphrodite duct; i. — intestine; l. — lung; ov. — oviduct; ov.gl. — oviducal gland; pc. — pericardium; pen. — penis; p.gl. — prostate gland; pn. — pneumostome; p.r.m. — penis retractor muscle; r. — rectum; ren. — kidney; r.o. — renal orifice; s.d. — secretory diverticulum; s.o. — sense organ; sp. — spermatheca; s.p. — secretory pore; s.v. — shell vesicle; u. — ureter; u.i.t. — uretero-intestinal tubule.  
Note: Scale divisions are in mm unless otherwise indicated.

## ANATOMICAL STUDIES

Live specimens from Hawdon River Forks, the type locality for *Reflectopallium pseudophyllum*, clearly show a triangular mantle area. This immediately places the species in the genus *Pseudaneitea* Cockerell, 1891, and as *R. pseudophyllum* is the type species for the genus *Reflectopallium*, this finding renders the genus invalid. I must therefore reduce *Reflectopallium* to synonymy with *Pseudaneitea*. The status of the four constituent species of the genus must now be examined.

*Pseudaneitea pseudophylla* (Burton, 1963) (Figs. 1, 2)

**External characters.** A moderately large species, up to 60 mm long. Colour brownish-grey mottled with black, papillae white-tipped. Skin finely granulate, with 2-3 low rounded papillae per side field, median and lateral grooves narrow, sometimes indistinct. Mouth ventral, at about 0.05 body length, small, oval, bordered anteriorly by a pair of oval preoral lobes, separated from sole by deep, narrow, transverse furrow. Head shield an equilateral triangle with base anterior, apex produced posteriorly to renal orifice at 0.28 body length; genital orifice — a short, narrow, slightly curved slit — marginal, lateral to right tentacle. Mantle area small, triangular, anterior section of right lateral margin very indistinct or lacking in preserved specimens. Renal orifice at median anterior apex covered by semicircular flap perforated by minute external pore of secretory diverticulum; pneumostome in right lateral apex of mantle area. Anus close to perinotum, lateral to renal orifice. From 14 to 18 narrow lateral grooves on each side, often bifid or trifid, arise on either side of head shield, mantle area, and median groove and run diagonally across back to hyponotum.

Dimensions of paratype: total length, 55 mm; maximum breadth, 15 mm; head to renal orifice, 17 mm; length of mantle area, 8 mm; anus to perinotum, 2 mm.

**Jaw and radula.** Jaw with central plate more than twice as long as broad; pronounced ventral median cusp projecting to level of wing tips. Rachidian tooth of radula generally reduced, with 1-2 cusps; lateral teeth with 3-5 cusps, the innermost one strongly produced.

**Reproductive system.** Genital orifice lateral to right tentacle in marginal groove of head shield, opening to muscular atrium. Penis short, muscular, convoluted, inserted into atrium on right side, narrowing to merge into vas deferens at insertion of penis retractor muscle. Vas deferens coiling back along penis to pass along dorsal aspect of short, muscular oviduct which carries spermatheca at 0.3 length, broadly convoluted oviducal gland on opposite side at 0.5 length, and small prostate and large albumen gland terminally. Gonad oval, lobular, sculptured to fit between intestinal folds, attached by convoluted hermaphrodite duct to distal tip of oviduct.

**Pallial system.** Kidney bilobed, flattened, abutting median saccular sense organ posteriorly, leading anteriorly to thin-walled, pocketed, quadruply-folded ureter arranged in arc around posterior and lateral margins of lung, then running anteriorly along medial aspect of lung to renal orifice. Uretero-intestinal tubule leaves ureter medial to pneumostome, curves posterior to pneumostome through lung tissue then ventrally from anterolateral aspect of lung to run posteriorly along rectum to enter intestine. Secretory diverticulum convoluted, running from secretory pore just posterior to renal orifice alongside ureter. Lung flattened, oval, with ventral sinus draining into thin-walled atrium which also drains kidney. Ventricle oval, muscular. Shell rudiments lacking, but a few small membranous shell vesicles close to renal orifice.

**Material examined.** Five specimens, Hawdon R., National Museum collection; 4 specimens, Hawdon R., Apr. 1978, D. W. Burton; 5 specimens, Hawdon R., Jan. 1981, D. W. Burton.

**Remarks.** Live specimens clearly show the triangular mantle area characteristic of the genus *Pseudaneitea*. However, even recently preserved specimens tend to show the condition seen in Figure 2c, in which the lateral margin of the mantle area becomes very hard to see and may disappear altogether. The apparent shape of the mantle area which results, and which led to the erection of the genus *Reflectopallium*, is thus a preservation

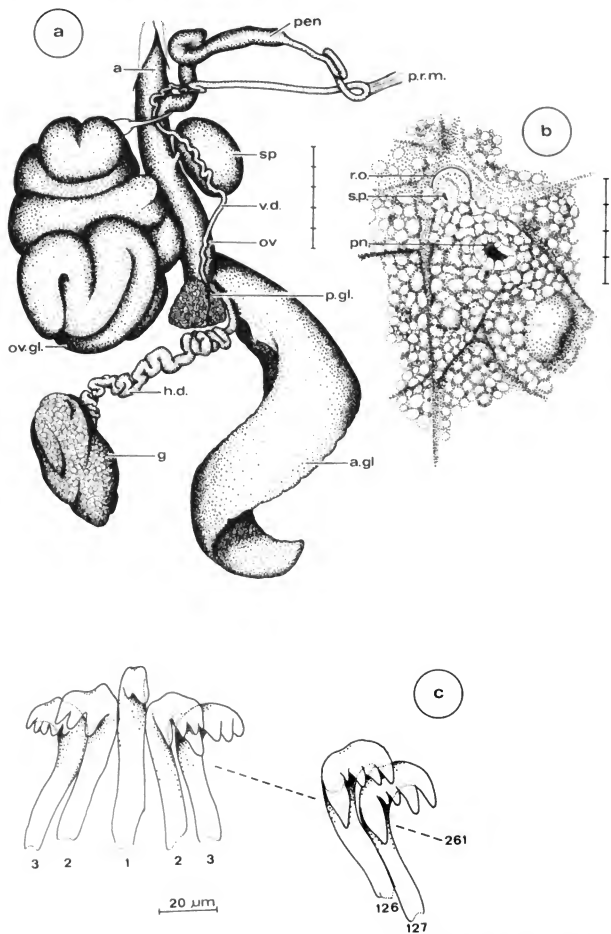


Fig. 2—(a-c) *Pseudaneitea pseudophylla*: (a) reproductive system; (b) mantle area, dorsal view, detail; (c) radula. For abbreviations, see Figure 1.

artefact. Placement of the species in the genus *Pseudaneitea* is much more satisfactory, as *P. pseudophylla* shows a clear relationship to both *P. dendyi* and *P. aspera* (Burton, 1980).

***Pseudaneitea papillata* (Burton, 1963)**

(ex *Reflectopallium papillatum* Burton, 1963)

Examination of the type specimen, held in the National Museum, shows that it is very similar to the paratypes of *P. pseudophylla* recently collected at Hawdon River. I therefore must reduce this species to synonymy with *P. pseudophylla*. This finding is a fortunate one, as the name *Pseudaneitea papillata* is already occupied by the type species for the genus *Pseudaneitea*.

*Material examined.* One specimen, Mt Algidus, coll. R. R. Forster, Feb. 1946.

***Pseudaneitea delli* (Burton, 1963)**

The status of this species is uncertain. It was described from a single specimen, and the mantle-area characteristics which led to its inclusion in *Reflectopallium* can no longer be seen in the type specimen. However, the type specimen, collected from Central Trio Is., Pelorus Sound, possesses a skin texture unlike that of any other athoracophorid, consisting of very numerous minute, distinctly spaced hemispherical papillae. The specimen does not resemble any other species found in the area. Obviously much more collecting is necessary.

*Material examined.* One specimen, the holotype, Central Trio Is., R. K. Dell, Sept. 1948, National Museum collection.

***Pseudaneitea martensi* (Suter, 1909)**

*Material examined.* 13 specimens, Auckland Is., National Museum collection.

In his first description of this species, Suter stated that the mantle area was triangular and hence placed the species in the then-subgenus *Pseudaneitea*. In his 1913 description of the species he mentioned that the mantle area was narrowly open on the right side but did not transfer the species from *Pseudaneitea*, even though in his diagnosis of the subgenus he stated that the mantle area was "distinct, triangular or rarely quadrangular". It was this discrepancy which led to the placement of the species in the new genus *Reflectopallium* in 1963. The species has recently been fully described (Burton, 1980). Of all the species originally included in *Reflectopallium*, it is this species which poses the greatest problem, as it is a fairly typical pseudaneiteid in all respects except the shape of the mantle area, the feature which is the main diagnostic character for the genus. There is now a mounting body of evidence which suggests that the generic criteria for the Athoracophoridae should be re-evaluated, but as an overall review of the group is currently under way (Barker, pers. comm.) I am reluctant to make any changes at this time. It seems that the most satisfactory solution to this particular problem is to return the species to the genus *Pseudaneitea*, pending a re-examination at a later date.

## DISCUSSION

The genus *Pseudaneitea* was first erected by Cockerell (1891) as a subgenus to accommodate Hutton's *Janella papillata*, with the triangular or rarely quadrangular shape of the mantle area the sole subgeneric criterion. Powell (1937) raised the subgenus to generic status without comment.

Over the last few years it has become obvious that the diagnostic criteria for the New Zealand and subantarctic athoracophorid genera leave much to be desired. Certainly slugs of the genus *Pseudaneitea* are quite different from those of the genus *Athoracophorus*, but the difference lies mainly in such characters as skin thickness, general body form, habitat and size, and in comparison with these, mantle area shape may have been accorded undue importance in the past. It does appear that there is an evolutionary trend towards elimination of the lateral groove of the mantle area, allowing the slugs to look more leaf-like, and possibly improving distribution of renal secretion over the surface of the back (Burton, 1980).

### ACKNOWLEDGEMENTS

I thank Dr F. M. Climo, National Museum of New Zealand, for making available the Museum collections of Athoracophoridae.

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## Fossil *Nothofagus* from the Longford Formation, Murchison, New Zealand

Aline M. Holden\*

Four Upper Miocene species of *Nothofagus* are described from the Longford Formation near Murchison, southeast Nelson. One of the species, *N. novae-zealandiae* (Oliver) comb. nov. has been recorded from Upper Miocene strata at Kaikorai, Dunedin; the remaining three, *N. bidentatus*, *N. oblonga* and *N. oliveri*, are new. The Longford Formation comprises floodplain deposits with basal estuarine beds and coal laid down by a meandering river with a high bed load. At least some species grew on the floodplain itself, in a moist, warm temperate to subtropical climate.

### INTRODUCTION

In New Zealand, investigations of plant macrofossils, especially those of the Upper Cretaceous and Tertiary, have been sparse and sporadic. A number of publications in the latter half of the nineteenth century dealt mostly with the systematics of specimens from localities of differing ages. Two of them, by Unger (1864) and Ettingshausen (1887), have formed the basis of most subsequent work on Cretaceous and Tertiary material. The lists and illustrations of New Zealand plant fossils drawn up by Hector, though widely circulated, include many species proposed as new which must be regarded as *nomina nuda* (Mildenhall, 1970).

Tertiary plant macrofossils were subsequently neglected. Berry (1926) described *Cocos* and proteaceous fruits from Miocene beds at Mangonui, North Auckland. Oliver (1928, 1936) and Pensler (1930) described fossil leaves from the Waipaoa Series of Ormond (Pleistocene), Kaikorai (Upper Miocene), and Pukemiro Colliery, Waikato (uppermost Eocene to early Oligocene). Nothing further of any significance has been published on Palaeogene or early Neogene plant macrofossils. The early work implied the presence of many north temperate forms which has not been confirmed by studies of plant microfossils (Couper, 1953). A re-evaluation of New Zealand Cretaceous and Tertiary macrofossils is needed to confirm the results of plant microfossil studies.

The problems of identifying fossil leaves were outlined by Mouton (1966) who proposed some solutions and called for a more detailed analysis of the leaf characters of living species as an aid to the identification of fossils. Mildenhall (1973) conducted an experiment involving the identification of living leaves from plaster moulds, and found that while distinctive forms were easily recognised, those with more subtle differences were often misidentified by experienced botanists. Where possible, I have assigned fossil species to extant genera. Although this practice has drawn criticism, particularly from Hughes (1963, 1976), there is no generally accepted alternative. It is followed here in the knowledge that the genera and species described are qualitatively different from living taxa because they are based on isolated organs, not on complete plants.

Grid references below refer to the New Zealand 1:50 000 metric map series (NZMS 260), the six-figures being prefixed by the sheet number. All New Zealand fossil record file numbers are prefixed by the 1:50 000 sheet number. Plant microfossils held at the N.Z. Geological Survey are prefixed by B; fossils held at Victoria University are prefixed

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by V, and specimens held in the type room there are given an additional catalogue number prefixed, in the case of plant macrofossils, by the code VH.

## MATERIALS AND METHODS

Various systems for the description of leaf form and venation have been published since Ettingshausen's pioneer work. That of Hickey (1973), as modified by Dilcher (1974), has been used throughout this study.

The fossils were catalogued and described in detail. Direct, oblique and reflected illumination were used to show up surface features. The best preserved specimens for each leaf type were selected for illustration. Drawings were prepared using a modification of a method described by Dilcher (1974). Acetate film was taped over the fossil, and the leaf outline and venation scratched onto the film using a sharp needle. A dissecting microscope was used to record fine detail. The drawing was rubbed with a soft pencil (grade 6B) to fill the scratches, taped to sheets of thin white paper, placed on a light table and traced onto tracing paper with ink.

Owing to the irregular surfaces of many of the fossiliferous blocks it was necessary to cut small pieces of acetate to fit, thus making Dilcher's photographic method of reproduction difficult. While the method is capable of producing fairly detailed drawings, scratching the acetate tends to obscure the finer details. These were drawn independently using a camera lucida fitted to a Leitz dissecting microscope.

For identification, comparisons were made with specimens of native and exotic plants collected by the author and with material in herbaria at the Botany Department, Victoria University; the National Museum, Wellington; and at the Centre de l'Office de la Recherche Scientifique et Technique d'Outre-Mer, Nouméa, New Caledonia. They were also compared with fossil plants collected by the late Dr W. R. B. Oliver from Ormrod and Kaikorai and held at the National Museum, Wellington, and with fossils from the Waikato area collected by W. H. A. Pensler and held at the New Zealand Geological Survey, Lower Hutt.

## GEOLOGICAL SETTING

The Longford Formation is a thick sequence of freshwater sediments exposed near Murchison, southeast Nelson (Fig. 1). The type section of the formation is in Nuggety Creek, and the name is taken from nearby Longford Junction where the sediments are well exposed and easily accessible (Henderson, 1929; Fyfe, 1968). The 1:250,000 geological map (Bowen, 1964) shows the formation extending from the headwaters of Coal Creek about 1 km west of the Owen River in the north, to the upper Maruia Valley in the south. It occupies the axis of a tightly-folded syncline approximately 70 km long by 10 km wide. 3200 m of sediment are exposed in the type section, but the top is nowhere known. Dips reach 80° along the flanks of the syncline and lessen towards the axis. No major faults disturb the sequence.

The formation is well exposed in river valleys, and the more resistant conglomerate bands form prominent strike ridges which can sometimes be traced for several kilometres in aerial photographs. In the creek beds, differential erosion has left the conglomerate and sandstone forming shallows and rapids, while deeper pools overlie the softer mudstones and shales. The formation contains conglomerates, grits, banded sandstones, shales and coal seams. Coals are commoner in the basal part of the sequence (Henderson, 1929), but plant fossils are abundant throughout in the finer sediments. Longford beds conformably overlie massive marine sands of the Upper Mangles Formation. A sandstone band, with the estuarine bivalve *Chione*, turritellids and other mollusca, forms an easily-recognised base in the formation (R. P. Suggate, pers. comm.). This bed has been located in several sections through the lower part of the formation (for example, at Blue Duck Creek), but has not been found in the type section at Nuggety Creek, where the base of the formation is taken as the first conglomerate band (Fyfe, 1968).

Sedimentary processes that formed the Longford Formation were cyclic with regular deposition of thick bands of conglomerate alternating with sandstones, siltstones and

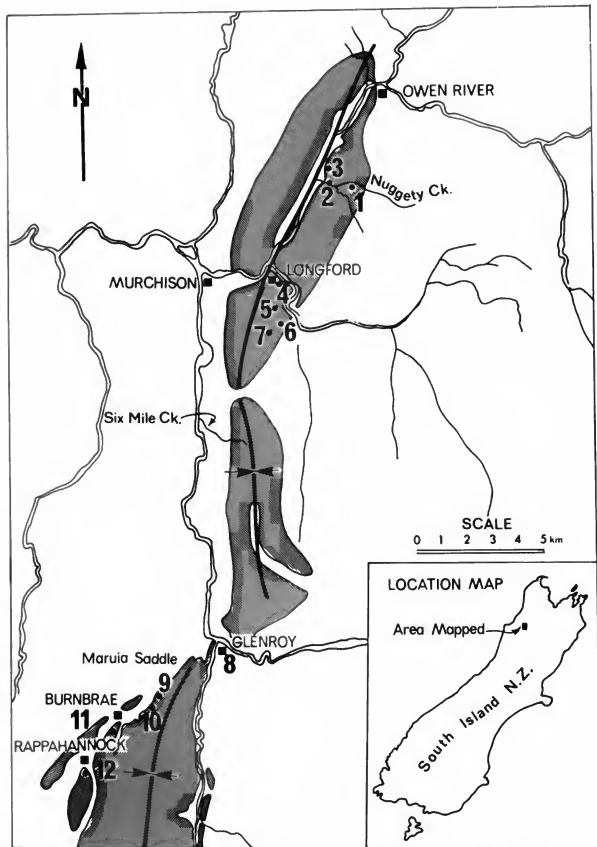


Fig. 1—Longford Formation (after Bowen, 1964). Localities 1 to 3 are in Nuggety Creek; 4 is the Dress Circle, Longford; 5 is the Mangles Valley television translator track; 6 and 7 are in Blue Duck Creek; 8 is the cutting by the Glenroy River bridge; 9 and 10 are on the Maruia Saddle road; 11 is at Burnbrae (Frog Flat Junction) and 12 at the Rappahannock road junction.

shales, the latter often rich in organic matter. The depositional cycles, up to 10 m thick, are predominantly asymmetric, and appear to be similar to fining-upwards cyclothems in the Old Red Sandstone of the British Isles (Allen, 1970). Sandstones at Longford (M29/579347) show some cross-bedding and scouring, and thin, well-defined laminae are present throughout in both sandstones and shales. Siltstones and mudstones make up a considerable proportion of each depositional cycle, a feature more consistent with meandering than braided rivers. Fining-upwards sequences of the type described above are generally held to result from the sedimentary processes associated with the high sinuosity migrating channels of meandering rivers (Visser, 1965; 1972; Collinson, 1978; Selley, 1978). Imbrication of the pebbles in the conglomerate, together with the presence of large pieces of wood, indicates channel deposition, while sedimentary structures observed in some of the sandstones are consistent with point bar deposits (Visser, 1965; Selley, 1978). The siltstones and shales probably represent overbank deposits on the floodplain surface.

Not all the sandstones show point bar structures, however. Massive sandstone overlying carbonaceous shale with a thick capping of fossil leaves at Nuggety Creek (M29/604410) appears to be the result of breaching of a levee during a time of flood which deposited a sand sheet in a back swamp area (Duff *et al.*, 1967). There is little evidence of scouring here. The shale, with its covering leaf beds, appears to have been deposited in a lake or pool in quiet, probably stagnant water. Carpets of partly decayed leaves can be extremely resistant to disturbance, as can fine clays, and resist scouring. The overall grey colour of the unweathered Longford beds, coupled with the absence of desiccation structures, indicates deposition in a humid environment, with a high water table close to or above the depositional surface maintaining a reducing environment (Collinson, 1978). Humid floodplain deposits are associated with Permian Gondwana coals in Africa, India, Australia and Antarctica (Duff *et al.*, 1967). Point bar and overbank deposits have been identified in the Kapuni Formation (Eocene to Oligocene) of New Zealand (Hill and Collen, 1978). Rhythms described from the New South Wales coal measures (Duff, 1967) and the Beacon Group of Antarctica (Barrett, 1965) are generally comparable with those from Murchison, except that there is more conglomerate in the Longford Formation. The large proportion of conglomerate may be due to a short distance between the source of the detritus and the site of deposition.

Rivers with a high bed load normally form low-sinuosity braided channels. The presence of dense vegetation on the floodplain, however, may increase bank resistance to such an extent that meandering is induced (Miall, 1977). This has been exploited in flood control schemes (Nevins, 1969). The abundant plant remains in the overbank facies of the formation indicates just such a heavily vegetated floodplain. Breaching of levees and channel migration are not the only possible causes of the observed sedimentary cycles. Westoll (1968), lists a number of other possible causes, including episodic or continued crustal deformation, eustatic changes in sea level, climatic change, compaction and subcompaction of sediments and isostatic adjustments of land levels. Of these the most likely to be encountered in Tertiary deposits is subsidence owing to compaction of sediments and crustal deformation. It is known that regional subsidence was taking place at the time the Longford beds were deposited, and it is possible that this was at least in part episodic, associated with movements on the Alpine Fault. If this was the case, depression could have resulted in the formation of extensive coastal and lowland swamps with rejuvenation of the source resulting in coarser material being supplied periodically, but a detailed sedimentological investigation is beyond the scope of this study.

To summarise, the Longford beds appear to have been deposited on the floodplain of a meandering river with a high bed load. There were highlands of at least moderate relief at no great distance, and rainfall was sufficient to maintain a high water table.

## AGE

Fyfe (1968) suggested a possible Taranakian age for most of the Longford Formation, based on a Waiuan (Southland Series, Middle Miocene) age inferred from sparse microfaunas in the underlying Upper Mangels Formation. Longford beds in the Upper

Maruia Valley were mapped by Bowen (1964) as Taranakian to Wanganui (Nukumaruan Stage). The Wanganui age for the upper part of the sequence in the Rappahannock area was based on a lithological correlation with the Old Man Gravel of the Reefton area and has been confirmed by a pollen flora (D. C. Mildenhall, pers. comm.). The bulk of the formation is, however, older.

Bowen (1964) considered a Waiau (Late Southland, Middle Miocene) age possible for the lower part of the Longford Formation in the Murchison area. Land temperatures were warmer than at present, at least at low altitudes (see discussion below). As there is evidence for a cold episode during the Kapitean (Kennett, 1967), it seems unlikely that these beds are younger than Tongaporutuan (early Upper Miocene). The evidence is not conclusive, however, and cannot be confirmed by palynology (D. C. Mildenhall, pers. comm.) because of a total lack of pollen assemblages preserved in the higher-rank sediments.

## CLIMATE

The assumption that abundant *Nothofagus* is evidence for a cool climate (Oliver, 1936) cannot be accepted. The four species represented in the Longford Formation had large leaves and are comparable to the present-day species of New Caledonia and New Guinea, where they grow in tropical montane forests with a nearly frost-free climate and more or less constant humidity (van Steenis, 1971a; 1976). In the southeast of New Caledonia *Nothofagus* grows at altitudes as low as 200 m on the Plaine des Lacs (van Steenis, 1971b).

Associated with *Nothofagus* in the Longford flora are members of the Lauraceae, Proteaceae, Sapindaceae, Sapotaceae and Monimiaceae (personal observation), families that are all mainly tropical or subtropical in distribution. By contrast, temperate plants are poorly represented. Considering the large number of warmth-loving plants found in the Longford Formation, a climate at least as warm as that in the latitudinal range 30 to 35° S today is indicated (personal observation). From pollen assemblages, McQueen *et al.* (1968) proposed a warm temperate to subtropical climate at low levels during Southland and Taranaki times, with hills or mountains inland supporting a cool climate vegetation.

## COLLECTIONS EXAMINED

The material studied is contained in the following collections: New Zealand Geological Survey, Lower Hutt; B2, Nuggety Creek, M29/604410, coll. R. P. Suggate, D. Kear, E. T. Annear and W. A. Sara, 1951; B7, Dress Circle, Longford, M29/579347, S. M. Bell and R. P. Suggate, 1949; B1119, recollection from Dress Circle by D. C. Mildenhall *et al.*, 1978. Victoria University of Wellington; V2825, Dress Circle, Longford, M29/579347; V2826, Blue Duck Creek, M29/589347; V2827, Blue Duck Creek, M29/587314; V2828, Nuggety Creek, M29/616404; V2829, Nuggety Creek, M29/606409; V2830, Nuggety Creek, M29/604410; V2831, Maruia Saddle, M30/514078; V2832, Maruia Saddle, M30/512072; V2833, Burnbrae, L30/489059; Rappahannock, L30/474037; V2835, Mangles Valley television translator road, M29/585326; V2838, Glenroy River, M30/550113, all collected by A. M. Holden and J. D. Collen, 1979; V2836, Dress Circle, Longford, M29/579347, Brett Dawson, 1979.

## SYSTEMATIC DESCRIPTIONS

### Family Fagaceae

Oliver (1936) recognised seven species of fagaceous leaves from Kaikorai, and he assigned them to the living *Fagus* and *Nothofagus* and a genus of extinct plants, *Parafagus* which he thought to be allied to *Quercus*. Subsequently (1950) he placed all forms with straight secondaries in *Nothofagus* and those forms with curved secondaries in *Parafagus*. Leaves of some New Caledonian *Nothofagus*, for example *N. codonandra* (Baillon) van Steenis (Fig. 3.4) and *N. equilateralis* (Baumann-Bodenheim) van Steenis, often have curved secondaries. This character does not seem to be sufficiently constant to maintain Oliver's fossil genus.

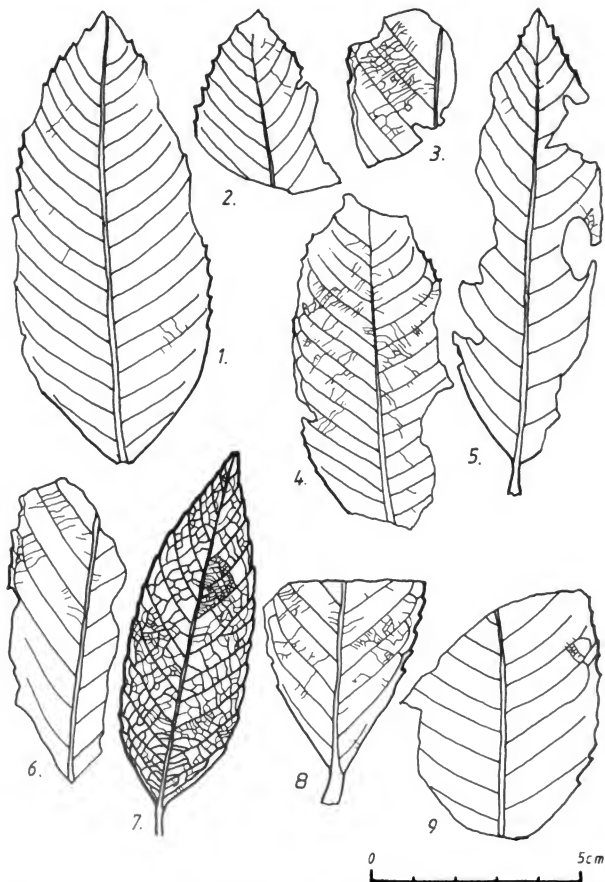


Fig. 2—1, 2, 5, *Nothofagus novae-zealandiae* Oliver. 1, VH 93, 2, B2/26; 5, B7/64. 3, 4, 6, 8, 9, *Nothofagus bidentatus* sp. nov. 4, B2/54, Holotype; 3, B7/36; 6, B7/14; 8, VH 96, Paratype; 9, VH 98. 7, *Nothofagus discoidea* (Baumann-Bodenheim) van Steenis. Haute Vallee du Thi, New Caledonia.

I have examined the type material of *Parafagus* held at the National Museum and consider that the leaves do not differ significantly from *Nothofagus*. All fossil fagaceous leaves, therefore, are here assigned to *Nothofagus*.

### *Nothofagus* Blume

Leaves simple, microphyll to mesophyll, generally elliptic or oblong; margin toothed or entire; venation craspedodromous or semi-craspedodromous, secondaries regularly spaced, more or less parallel, straight or somewhat curved; tertiary veins diverging at right angles, orthogonal reticulate or percurrent; highest order venation fifth, higher order venation orthogonal, areoles small, perfect, orientated.

Type: *Nothofagus betuloides* (Mirb.) Oerst., southern South America.

Included in *Nothofagus* Blume are those New Zealand Upper Cretaceous and Tertiary fossils assigned to *Fagus* L. and *Parafagus* Oliver. Four species are described from the Longford Formation: *Nothofagus novae-zealandiae* (Oliver) comb. nov., *N. bidentatus* sp. nov., *N. oblonga* sp. nov. and *N. oliveri* sp. nov. *N. novae-zealandiae* and *N. bidentatus* resemble the Oligocene *N. ninnisiana* (Unger) Oliver.

The abundance of beech leaves in the leaf layer capping a carbonaceous shale at Nuggety Creek described above indicates the presence of stands of beech on the floodplain itself. *Nothofagus* today is generally considered to be a montane plant, only reaching low levels in the cool, wet climates of southern New Zealand and South America. It was not so in the Tertiary, possibly because of different climatic patterns particularly in seasonal rainfall.

*Nothofagus novae-zealandiae* (Oliver) comb. nov. (Fig. 2.1, 2.2, 2.5)

*Fagus novae-zealandiae* Oliver, 1936: 289. (Fig. 4.)

*Fagus maorica* Oliver, 1936: 290. (Fig. 5.)

Mesophyll, 110 to 115 mm long by 35 to 45 mm wide; oblong to elliptic, somewhat narrow; apex acuminate to attenuate; base cuneate; margin serrate, teeth fairly large, acute, straight sided or with upper side concave, simple, mostly one per secondary vein, sinus rounded, spacing more or less uniform around entire margin; glands laminar; petiole short, moderately thick, venation craspedodromous, simple; midrib weak to moderate, straight, secondaries at least 13 pairs, alternate, uniformly spaced c. 5-7 mm apart, angle of divergence more or less uniform, narrow to moderate, 45-50°, straight to slightly curved, weak near apex otherwise moderate; tertiary veins weak, percurrent, at right angles to secondaries.

The Longford fossils closely resemble *Fagus novae-zealandiae* Oliver from Kaikorai, and also a second species, *F. maorica* Oliver from the same locality. From examination of Oliver's specimens in the National Museum the two species do not appear to be separable, and in an unpublished manuscript held at the Geological Survey Library, Lower Hutt, Oliver himself synonymised them. The type specimen has been broken off at the base, although this is not apparent from Oliver's published illustration or description. Close examination of the specimen shows faint traces of at least two more secondaries on the matrix below the base as illustrated by Oliver on the right hand side of the leaf. Comparison of the Longford specimens has been made with the holotype of *N. novae-zealandiae* only as the designated paratypes do not all correspond with the holotype.

Holotype: WELT 44482 in the National Museum, Wellington, W. R. B. Oliver, 1936, from Kaikorai.

Longford specimens: VH93, Longford, M29/579347, V.U.W.; VH94, Nuggety Creek, M29/604410, A. M. Holden & J. D. Collen, 1979; B2/26, B2/27, Nuggety Creek, M29/604410; B7/64, Longford, M29/579347, S. M. Bell and R. P. Suggate, 1949.

Other material examined: Specimens in the National Museum of *F. novae-zealandiae* and *F. maorica* from Kaikorai, W. R. B. Oliver, 1936.

*Nothofagus novae-zealandiae* has also been reported from Upper Miocene/Pliocene andesitic tuffs of the Beeson's Island Volcanics on Great Barrier Island (Thompson,

1960), and from mid-Pliocene rhyolitic tuffs of the Whitianga Group (Wainora Formation) in the Table Mountain area of the Coromandel Peninsula (Hayward, 1974).

***Nothofagus bidentatus* sp. nov.** (Fig. 2.3, 2.4, 2.6, 2.8, 2.9, 4.2, 4.3)

Mesophyll, 100 to 150 mm long by 35 to 55 mm broad; symmetrical, more or less oblong, somewhat narrow; apex acuminate to attenuate; base cuneate; margin more or less undulate, serrate, teeth acute to obtuse, straight sided, generally two per secondary vein, vein running to sinus, spacing uniform around complete margin; glands laminar; petiole short, stout; venation craspedodromous to semi-craspedodromous; midrib weak to moderate, straight; secondaries at least 15 pairs, alternate, more or less uniformly spaced 5 to 9 mm apart, diverging at moderate angle, straight or somewhat curved, joining superadjacent at more or less right angles, branch running to second tooth, moderately thick; tertiaries orthogonal reticulate or percurrent forked, crossing at right angles between secondaries, oblique to midrib, predominantly alternate, fairly close; higher order venation orthogonal, fairly thick, highest order fifth; areoles well-developed, orientated, quadrangular, small.

The fossils resemble juvenile leaves of *N. moorei* (F. Mueller) Krasser from Australia in shape, toothing, and venation, but are larger. They also resemble adult leaves of *N. discoidea* (Baumann-Bodenheim) van Steenis from New Caledonia, except that in the latter there is generally only one tooth per secondary vein (Fig. 2.7). The leaf is also similar to that of *N. novae-zealandiae*, the main difference being the arrangement of the marginal teeth and the semi-craspedodromous venation. The species is so named because of the two marginal teeth to each secondary vein.

**Holotype:** B2/51, Longford Formation, Nuggety Creek, M29/604410, R. P. Suggate, D. Kear, E. T. Annear, and W. A. Sara, 1951.

**Paratypes:** VH 95, VH 96, VH 97, Longford Formation, Dress Circle, Longford M29/579347, collected by A. M. Holden and J. D. Collen, January 1979.

**Other material examined:** B2/19, 20, 23, 37, 45, Nuggety Creek, M29/604410, R. P. Suggate, D. Kear, E. T. Annear, and W. A. Sara, 1951. B7/12, 13, 15, 20, 25, 31, 36, 42, 52, 54, 55, 59, 63, Longford, M29/579347, S. M. Bell and R. P. Suggate 1949; V2829/3, 5, 7, 11, 26, Longford, M29/579347, collected by A. M. Holden and J. D. Collen, January 1979.

***Nothofagus oblonga* sp. nov.** (Fig. 3.3, 3.6, 3.7, 4.1.)

Microphyll to small mesophyll, 70 to 100 mm long by 20 to 30 mm broad; oblong to elliptic, narrow; apex obtuse to rounded; base cuneate; margin entire, revolute; petiole not preserved. Venation pinnate, semi-craspedodromous, midrib stout, straight, secondaries at least 7 pairs, alternate, regularly spaced, 7-9 mm apart, diverging at moderate to wide angle, curved, moderately thick; tertiaries orthogonal reticulate to percurrent forked, oblique to midrib. Higher order venation orthogonal, highest order fifth; areoles small, well-formed, quadrangular, orientated.

The leaf resembles in shape, margin and venation the New Caledonian species *N. codonandra* (Fig. 3.4) and *N. equilateralis*. Descriptions by van Steenis of *N. rubra* and *N. brassii* in the Flora Malesiana (van Steenis, 1976) suggest that this fossil form may also resemble these New Guinea species, but specimens have not been available for direct comparison. The name refers to the oblong shape of the leaf chosen as type specimen.

**Holotype:** B7/56, Longford Formation, Dress Circle, Longford, M29/579347, collected by S. M. Bell and R. P. Suggate, 1949.

**Paratypes:** B7/28 and B7/64, Longford, M29/579347, collected by S. M. Bell and R. P. Suggate, 1949.

**Other material examined:** B7/6, 15 and 34, Longford, M29/579347, collected by S. M. Bell and R. P. Suggate, 1949; B2/60, Nuggety Creek, M29/604410, R. P. Suggate, D. Kear, E. T. Annear, and W. A. Sara, 1951.



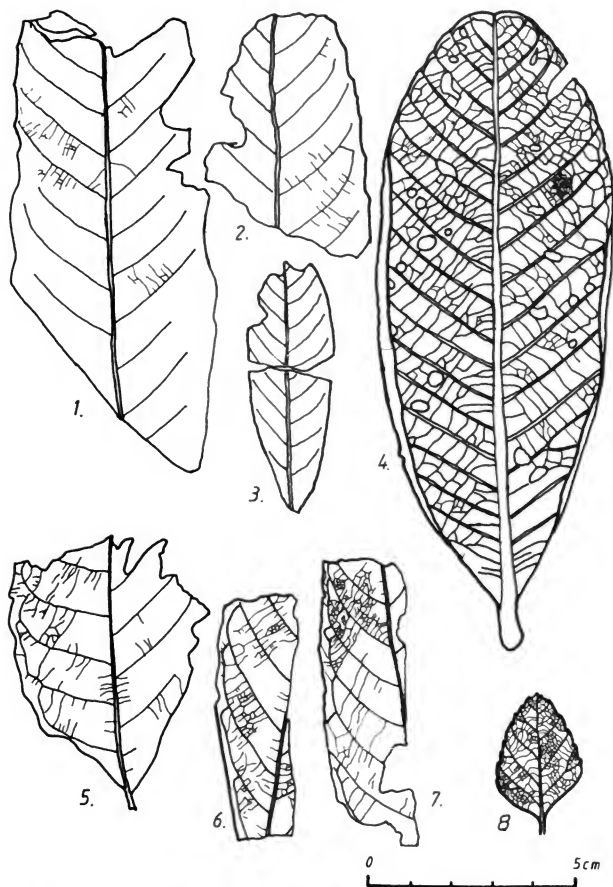


Fig. 3—1, 2, 5, *Nothofagus oliveri* sp. nov. 1, B2/49, Holotype; 2, B2/59A, paratype; 5, VH99. 3, 6, 7, *Nothofagus oblonga* sp. nov. 3, B7/56, Holotype; 6, B7/28, Paratype; 7, B7/15. 4, *Nothofagus codonandra* (Baillon) van Steenis. Montagne des Sources, New Caledonia. 8, *Nothofagus fusca* (Hooker f.) Oerst. Maruia saddle, southeast Nelson.

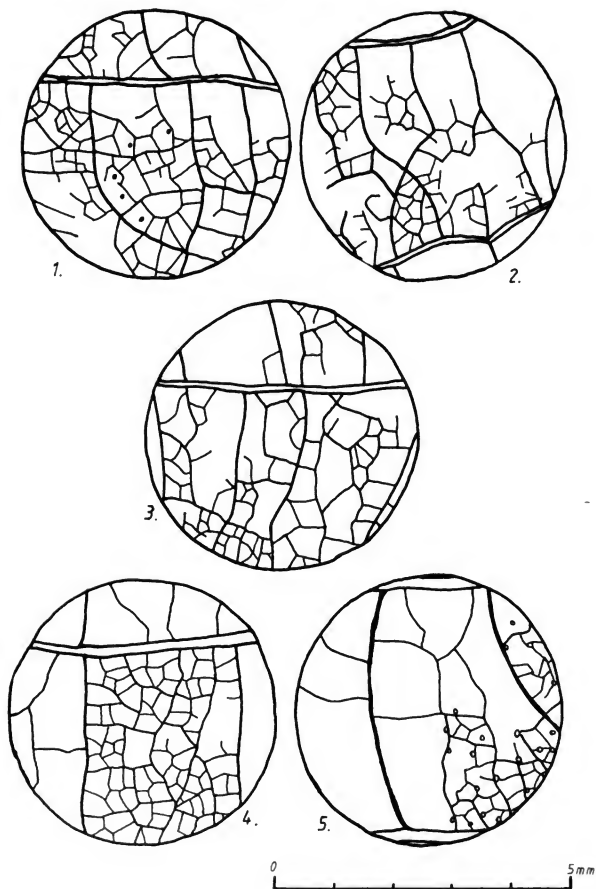


Fig. 4—Camera lucida drawings of fine venation of living and fossil *Nothofagus*. 1, *N. oblonga*; 2, 3, *N. bidentatus*; 4, *N. discoidea*; 5, *N. codonandra*.

***Nothofagus oliveri* sp. nov.** (Fig. 3.1, 3.2, 3.5.)

Mesophyll, 100 to 170 mm long by 60 mm broad; more or less narrow oblong, apex obtuse to acute; base probably cuneate; margin serrate, teeth obtuse, simple, two per secondary vein, sinus rounded, more or less uniformly spaced around complete margin, margin often strongly recurved and teeth obscure; glands laminar; venation pinnate, craspedodromous, or semi-craspedodromous; midrib moderate to weak, straight; secondaries at least 11 pairs, alternate, regularly spaced 7 to 11 mm apart, diverging to moderate to wide angle, 50 to 65°, more or less uniform, curved, joining superadjacent at right angles, moderately thick, branch to second tooth; tertiaries orthogonal reticulate or percurrent forked, oblique to midrib, crossing at right angles between secondaries, predominantly alternate, close; higher order venation orthogonal, rather thick, highest order fifth; areoles well-developed, oriented, quadrangular, small.

The fossil leaves have the characteristics of *Nothofagus*. The strongly recurved margins and obscure teeth of some specimens suggest the presence of both adult and juvenile leaves. While distinct juvenile leaf forms are not a feature of Recent New Zealand species, they are found in *N. moorei* from Australia, which the fossil resembles although it is much larger, and in various New Caledonian species. In the case of *N. baumanii* the margin of juveniles are regularly and strongly toothed, while adults have recurved, more or less entire margins. Although fairly common, this species is less abundant than *N. bidentatus*. The species is named after the late Dr W. R. B. Oliver, who made several contributions to New Zealand fossil botany.

**Holotype:** B2/49, Longford Formation, Nuggety Creek, M29/604410, R. P. Suggate, D. Kear, E. T. Annear, and W. A. Sara, 1951.

**Paratypes:** B2/59 and B2/59A (counterpart), B2/23, Nuggety Creek, M29/604410, R. P. Suggate, D. Kear, E. T. Annear, and W. A. Sara, 1951.

**Other material examined:** Other impressions on B2/49; B7/69, Dress Circle, Longford, M29/579347, collected by S. M. Bell and R. P. Suggate, 1949; V2825 Nos. 24 and 29, Longford, M29/579347, collected by A. M. Holden and J. D. Collen.

**ACKNOWLEDGEMENTS**

The work described in the foregoing account forms part of a study towards the degree of Doctor of Philosophy at Victoria University of Wellington. I would like to thank the following people for their assistance: Dr Ph. Morat, chief botanist at ORSTOM, Noumea, for access to the herbarium; Dr Gordon McPherson of Noumea for his help in the field in New Caledonia; my supervisors, Professor P. Vella and Drs J. D. Collen and J. W. Dawson, for their encouragement and for critically reading the manuscript; Dr P. J. Brownsey for access to the National Museum herbarium; Sir Charles Fleming and Drs D. R. McQueen and D. C. Mildenhall for many helpful discussions; and Mrs V. Hibbert for her patient typing of the manuscript.

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## Fossil Lauraceae and Proteaceae from the Longford Formation, Murchison, New Zealand

Aline M. Holden\*

Seven species of fossil lauraceous leaves from the Longford Formation (Mid to Upper Miocene), Murchison, southeast Nelson, are described. Of these, *Beilschmiedia tarairioides* Pens. is also known from the late Eocene to early Oligocene coal measures of the Waikato; *Cinnamomum miocenicum*, *Cryptocarya tutakia*, *C. longfordiensis*, *C. murchisoniensis*, and *Litsea dawsoniana* are new. Three species of proteaceous leaves are also described. *Knightia oblonga* Oliver was described from Upper Miocene beds at Kaikorai, Dunedin. *Kernadecia merytifolia* and *Longfordia banksiaefolia* are new species, and *Longfordia* is a new genus.

### INTRODUCTION

The plants described in this account grew in association with *Nothofagus* in lowland forest during late Mid to early Upper Miocene times (Holden, 1982). Four genera and seven species of Lauraceae have been recognised in the Longford Formation (Figs. 1, 2) and, though less abundant than *Nothofagus*, they appear to have formed an important element in the Longford flora. Proteaceae (Figs. 3, 4) appear not to have been numerous but include three genera, each represented by one species.

Both the Lauraceae and the Proteaceae have long fossil histories and are known either as macrofossils or as pollen from Upper Cretaceous onwards (Ettingshausen, 1887; Couper, 1953, 1960). Both families are thermophilic. At present only *Beilschmiedia tawa* (A. Cunn.) Benth. & Hook. f. ex Kirk (Lauraceae), and *Knightia excelsa* R. Brown (Proteaceae) are found farther south than 39° in New Zealand and neither extends beyond 42° (Allan, 1961).

The six-digit grid references given refer to sheets M29, M30, and L30 on the New Zealand 1: 50 000 topographic map series (NZMS 260). All New Zealand fossil record file numbers (f numbers) are prefixed by the 1: 50 000 sheet number. Plant macrofossils held at the N.Z. Geological Survey have catalogue numbers prefixed by B. Fossils held at Victoria University of Wellington have numbers prefixed by V, and specimens of plant macrofossils in the type room there have numbers prefixed by VH.

### FAMILY LAURACEAE

The Family Lauraceae is represented in New Zealand at present by four species in three genera (Allan, 1961). Of these, *Cassytha paniculata* R. Brown is a leafless parasitic liane; the others, *Beilschmiedia tarairi* (A. Cunn.) Benth. & Hook. f. ex Kirk, *B. tawa* and *Litsea calicaris* (A. Cunn) Benth. & Hook. f. ex Kirk, are forest trees.

The oldest New Zealand fossils confidently assigned to the Lauraceae are leaf impressions described as *Cinnamomum haastii* by Ettingshausen (1887) from the Upper Cretaceous at Pakawau, northwest Nelson, although *C. intermedium* from Shag Point, Otago, may be older. Lauraceous macrofossils have been reported in many Tertiary deposits (Ettingshausen, 1887; Oliver, 1928; Penseler, 1930). Lauraceous pollen is difficult to distinguish from that of some other families (D.C. Mildenhall, pers. comm.), but the record of *Beilschmiedia* pollen from the Miocene (Couper, 1953) is unsubstantiated.

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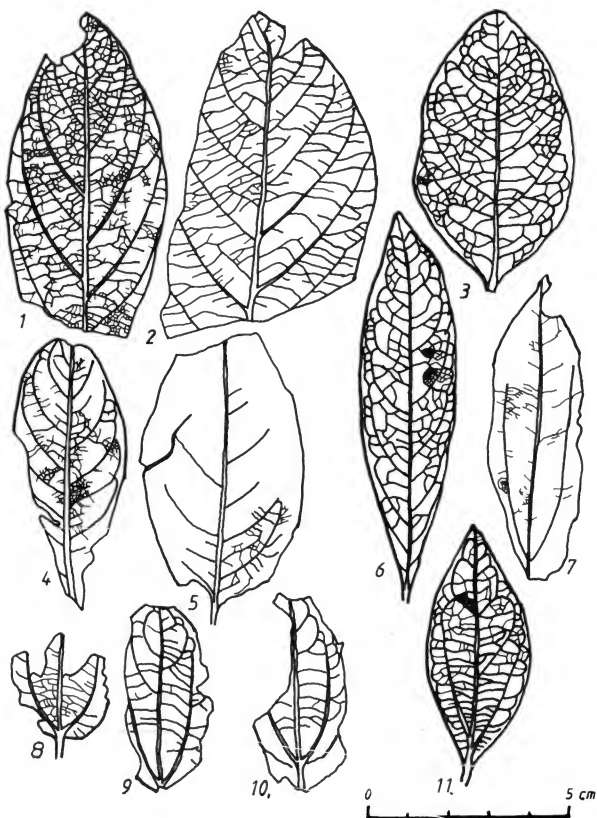


Fig. 1—Lauraceae. 1, 2 — *Litsea dawsoniana* sp. nov. (1: VH105, holotype; 2: B2/39, paratype). 3 — *Litsea calicaris* (A. Cunn.) Benth. & Hook. f. ex Kirk, Auckland. 4 — *Cryptocarya tutakiae* sp. nov. (4: B/1119 6, holotype; 5: B2/29, paratype). 6 — *Bielschmiedia laua* (A. Cunn.) Benth. & Hook. f. ex Kirk, Trentham, Wellington. 7 — *Cinnamomum miocenicum* sp. nov., VH 101, holotype. 8, 9, 10 — *Cryptocarya longfordiensis* sp. nov. (8: B7 43, paratype) 9: B7/70, holotype; 10: B2/54, paratype). 11 — *Cryptocarya triplinervis* R. Brown, Lord Howe Island.

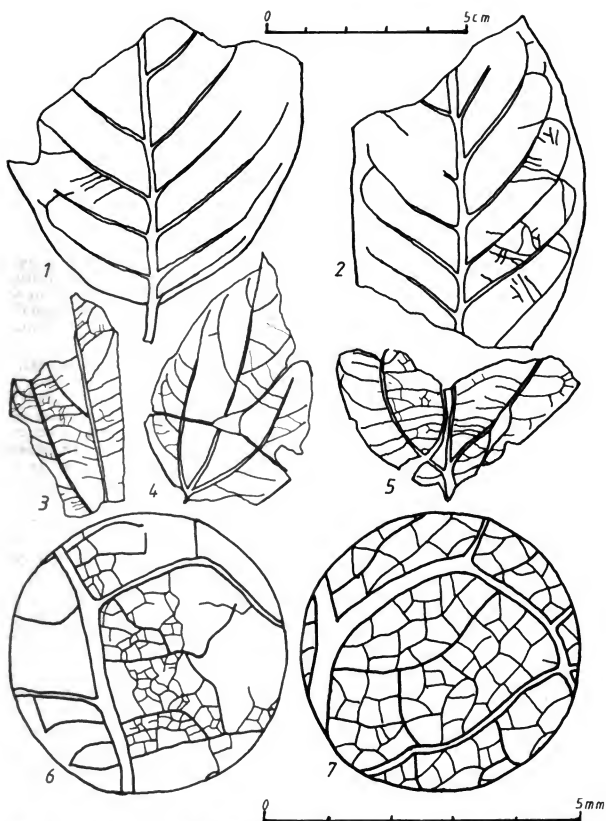


Fig. 2—Lauraceae. 1, 2 — *Bielschmiedia taraioides* Pensler (1: VH100; 2: B2/48). 3, 4 — *Cryptocarya murchisoniensis* sp. nov. (3: VH103; 4: VH/102, holotype). *Cryptocarya bulleriana* sp. nov., VH107, holotype. 6, 7 — Camera lucida drawings of fine venation (6: *Cryptocarya tutakiae*; 7: *Cryptocarya triplinervis*).



***Beilschmiedia* Nees**

Living species include trees and shrubs, mainly tropical. Leaves variously shaped, margins entire; venation pinnate, brochiodromous, usually with several enclosing secondary and tertiary arches, secondary veins sometimes branched, intersecondaries composite, tertiary veins reticulate or percurrent, higher-order venation random to more or less orthogonal; areoles perfect, small, polygonal, oriented.

The type species of genus *Beilschmiedia* is *B. roxburghiana* Nees.

**?*Beilschmiedia tarairioides* Penseler, 1930 (466: figs. 17-19, 43) (Figs. 2.1, 2.2)**

Mesophyll, fragments 70 to 85 mm long by 60 to 75 mm broad. Broadly oblong to elliptic, apex not preserved, base rounded, symmetrical, margin entire, plane, perhaps thickened; petiole fairly stout, c. 10 mm long. Venation pinnate, brochiodromous; midrib stout, straight or slightly curved; secondaries at least eight pairs, opposite below, becoming alternate above, 9 to 15 mm apart, closely spaced near the base becoming more distant above, angle of divergence from midrib moderate to wide, c. 50° to 80°, widest near base decreasing upwards, branched, curved, loop forming branches joining superadjacent at acute to right angles; intersecondaries composite; tertiaries weak, percurrent, diverging at an acute angle from the lower side and an obtuse angle from the upper side of the secondary, oblique to midrib, becoming more or less horizontal near margin. Higher-order venation not preserved.

The Longford fossils resemble Penseler's type specimen and other specimens held at the Geological Survey, Lower Hutt. The pattern of the secondary and tertiary veins is identical, and in both the Longford and the Waikato fossils the higher-order venation is too weak to be observable. There are strong similarities with the Recent *B. tarairi*, the fossils differing in the more rounded leaf base and weaker venation. In this respect the fossils are probably closer to the Australian *B. obtusifolia* (F. Muell. ex Meissn.) F. Muell. (see illustrations in Francis, 1970). Neither the Longford nor Penseler's Waikato fossils resemble the fossil *B. ovata* Oliver (Waipaoa Series, Pliocene) from Ormond, Poverty Bay.

**Holotype:** B56/6 (S14/f7005) from Pukemiro Colliery, Waikato, W. H. A. Penseler, 1930.

**Figured specimens:** VH100 (M29/f154), Dress Circle, Longford, M29/579347, A. M. Holden and J. D. Collen, 1979; B2/48 (M29/f579), Nuggety Creek, M29/604410, R. P. Suggate, D. Kear, E. T. Annear, and W. A. Sara, 1951.

**Other material examined:** B2/2 (M29/f8579), Nuggety Creek, M29/604410, R. P. Suggate, D. Kear, E. T. Annear, and W. A. Sara, 1951; B7/4 and B7/33 (M29/f8606) (counterparts), Dress Circle, Longford, M29/579347, S. M. Bell and R. P. Suggate, 1949; V2827 (M29/f150), Blue Duck Creek, M29/587314, A. H. Holden and J. D. Collen, January 1979.

All specimens except Penseler's holotype are from the Longford Formation, Mid to Upper Miocene.

***Cryptocarya* R. Brown**

Living species, trees or shrubs, mainly of tropical closed forests. Leaves simple, variously shaped, margins entire; venation pinnate, brochiodromous with enclosing tertiary arches or acrodromous, suprabasal, imperfect to perfect ("Cinnamomum-type" venation); in the latter case the lowest pair of secondaries from the midrib arise one third of the way or more up the lamina; tertiaries reticulate to percurrent, frequently strong; higher-order venation random to orthogonal, little differentiation into vein orders; areoles perfect, orientated, small, quadrangular to polygonal. (For illustrations showing the range of leaf form in Australasian members of the genus see Hyland (1971) and Kostermans (1974).)

**Lectotype:** *Cryptocarya glaucescens* R. Brown, Australia. The genus has not previously been recorded from New Zealand, but it may be represented by some fossils assigned to

*Cinnamomum* by early workers and by the Nukumaruan (Early Pleistocene) *Phyllites kaiwakaensis* McQueen (McQueen, 1954).

**?*Cryptocarya tutakiae* sp. nov.** (Figs. 1.4, 1.5, 2.6)

Microphyll to small mesophyll, 65 × 25 mm to 80 × 40 mm; elliptic to obovate; apex acute to emarginate, base cuneate, margin entire; petiole missing; venation pinnate, brochiodromous, with enclosing secondary arches; midrib moderate to stout, straight or slightly curved; secondaries irregularly spaced, at least 6 to 7 pairs, alternate, diverging at moderate to wide angle, 50° to 80°, more acute above, curved, moderately thick, loop-forming branches joining superadjacent at acute to right angles; intersecondaries compound, often more than one between each secondary; tertiaries diverging at mainly acute angles, percurrent, forked or retroflexed, alternate, 2 to 4 mm apart; higher-order venation more or less orthogonal, vein order not well differentiated; areoles perfect, orientated, small, quadrangular to polygonal.

The brochiodromous venation with enclosing secondary arches and more or less orthogonal fine venation not well differentiated into orders are typical of the Lauraceae. In leaf form and venation the fossil approaches the North Queensland *Cryptocarya obovata* R. Brown. I have also seen a similar leaf in drifted plant debris in a concretion containing a whale vertebra from the Tongaporutuan stage (Upper Miocene) at Putangirua Stream, Palliser Bay, Wellington Province.

**Holotype:** B1119/6 (M29/f8606A), Dress Circle, Longford, M29/579347, D. C. Mildenhall *et al.*, 1978.

**Paratype:** B2/29 (M29/f8579), Nuggety Creek, M29/604410.

The name is from Tutaki Survey District.

**?*Cryptocarya murchisoniensis* sp. nov.** (Figs. 2.3, 2.4)

Small mesophyll, size 70 × 45 mm; broadly ovate, widest near base, symmetrical; apex missing but probably acute to attenuate; base more or less rounded; margin entire; venation acrodromous suprabasal perfect; primaries three, strong, extending at least three-fourths of the way up the leaf, uniting with first pair of secondaries, laterals diverging at a narrow to moderate angle and running more or less parallel with the midrib; lowest secondaries from midrib arising just over half way up leaf, secondaries from laterals on outer side only, angle of divergence moderate, 50° to 65°, curved, joining superadjacent at acute to right angle forming marked loops; rather weak percurrent, straight to convex nerves between primaries, arising at acute to right angles; tertiary venation weak and somewhat obscure, but probably percurrent; higher order venation not preserved.

The species is fairly common. The venation pattern is characteristic of species of *Cinnamomum* and *Cryptocarya*. In view of the strength of the main nerves and secondaries the fossil is more likely to be a species of *Cryptocarya*.

**Holotype:** VH102 (M29/f154), Dress Circle, Longford, M29/579347, A. M. Holden and J. D. Collen, January 1979.

**Paratypes:** VH103, VH104 (both M30/f24), cutting at end of new bridge, true right bank, Glenroy River, Upper Matakiki Valley, M30/550113, A. M. Holden and J. D. Collen, January 1979.

**Other material examined:** V2832/9 (M30/f26), Maruia Saddle Road, on south side of summit, M30/512072, A. M. Holden and J. D. Collen, January 1979; B36/1, 2, 3, from the same locality.

The species is named after the township of Murchison.

***Cryptocarya longfordiensis* sp. nov.** (Figs. 1.8, 1.9, 1.10)

Microphyll, 40 × 22 mm; elliptic to ovate; apex missing but probably acute to obtuse, base obtuse to more or less rounded; margin entire; petiole normal, fairly stout, at least 10 mm long; venation acrodromous suprabasal perfect; primary nerves three, weak to

moderate, laterals extending about two-thirds to three-quarters of the way up leaf, secondaries from laterals on outer side only, angle of divergence wide to right angle, 65° to 90°, moderately thick, curved, joining superadjacent at acute angle to form prominent loops; intersecondaries compound; strong nerves passing between the primaries convex, some forked; tertiaries percurrent, straight or sinuous, crossing more or less at right angles, alternate, thick; higher order venation obscure, weak.

This type of venation is found in *Cinnamomum* and *Cryptocarya*. Tertiary venation in *Cinnamomum* is usually rather weak, and the thick tertiaries of the fossil are more consistent with *Cryptocarya*. The leaf bears a strong resemblance to that of *C. triplinervis* R. Brown (Fig. 1.11) of north Queensland and Lord Howe Island, the main difference being the more or less rounded base of the Longford fossils as opposed to the cuneate base of the living species. There is also some resemblance to *Cinnamomum haastii* Ett. from the Upper Cretaceous at Pakawau, but I have not been able to examine Ettingshausen's specimen.

*Holotype*: B7/70 (M29/f8606), Dress Circle, Longford, M29/579347, S. M. Bell and R. P. Suggate, 1949.

*Paratypes*: B2/54 (M29/f8579), Nuggety Creek, M29/604410, and B7/43, B7/49 (both M29/f8606) (counterparts), Dress Circle, Longford.

*Other material examined*: B7/75 and B7/36 (both M29/f8606) from Dress Circle, Longford, B36/2, B36/3 from Maruia Saddle Road, south side of summit, M30/512072.

The species is named after Longford Junction, where the Longford Formation is exposed.

*?Cryptocarya bulleriana* sp. nov. (Fig. 2.5)

Mesophyll, only the base is preserved, but leaf at least 65 mm broad; probably somewhat broad ovate; apex missing; base rounded; margin entire; venation acrodromous, suprabasal; primaries 3, laterals arising at moderate angle and running more or less parallel to midrib; secondaries arising from laterals at wide to more or less right angles, 65-90°, 5 to 10 mm apart, on outer side only, curved, joining superadjacent at acute to right angles forming prominent loops; strong percurrent nerves between the primaries; higher order venation orthogonal.

The leaf base resembles that of *C. munchisoniensis*, but the leaf appears to have been much larger and the percurrent veins between the primaries and the fine venation much stronger. The fossil is regarded as a distinct species.

*Holotype*: VH107 (M29/f155), from bulldozed track to local television translator, Mangles Valley, M29/585326; A. H. Holden and J. D. Collen, January 1979.

*Cinnamomum* Blume

Living species, trees of closed forests, mainly tropical, leaves simple, of various shapes, margins entire. Venation acrodromous suprabasal imperfect to perfect (*Cinnamomum*-type venation), or sometimes pinnate, brochiodromous or apparently so; secondaries arising from midrib in *Cinnamomum*-type leaves generally half way or more up the leaf, somewhat weak; tertiaries percurrent, weak; higher order venation random to orthogonal, not well-differentiated into orders; areoles perfect, orientated, small, quadrangular to polygonal.

*Lectotype*: *Cinnamomum zeylandicum* Blume, Sri Lanka. The so-called *Cinnamomum*-type venation is not found in all species of *Cinnamomum* and is not restricted to the genus. In some cases a rather extreme form of this pattern causes a superficial resemblance to pinnate venation, as for example in *C. camphora* (L.) Presl. Several fossil species of *Cinnamomum* have been described from the Cretaceous and Tertiary in New Zealand (Ettingshausen, 1887; Penseler, 1930), but some of the identifications seem doubtful.

*?Cinnamomum miocenicum* sp. nov. (Fig. 1.7)

Microphyll to small mesophyll, leaf 85 mm long by 25 mm broad, narrow oblong, apex acuminate-attenuate; base not preserved; margin entire; venation acrodromous suprabasal perfect; primaries three, laterals weak; secondaries from midrib few, lowest

arising about three-fourths of way up leaf, those from laterals on outer side only, angle of divergence wide,  $65^{\circ}$  to  $90^{\circ}$ , weak, curved, joining superadjacent at right angles; percurrent veins between primaries weak; higher order venation, where visible, orthogonal; areoles perfect, orientated, small, quadrangular to polygonal.

The venation pattern is of undoubted *Cinnamomum* type, and the overall weakness of the veins is consistent with *Cinnamomum*. The fossil closely resembles the leaves of *C. laubatii* F. Muell. from Queensland. The Eocene to Oligocene fossils *C. intermedium* Ett. from Shag Point and Redcliffe Gully appear to have stronger fine venation, but I have been unable to make a direct comparison with Ettingshausen's holotype.

**Holotype:** VH101 (M29/f154), Dress Circle, Longford, M29/579347, A. M. Holden and J. D. Collen, January 1979.

The species is named after the Miocene period.

### *Litsea* Lamarck

Living species, mainly trees and shrubs of tropical forest or maquis; leaves simple, variously shaped, margins entire; venation pinnate, brochiodromous, generally with enclosing secondary arches; secondaries often branched; tertiaries reticulate to percurrent, often strong; higher-order venation orthogonal or random, not well differentiated; areoles perfect, orientated, small, quadrangular to polygonal.

**Type species:** *Litsea chinensis* Lamarck.

Fossils of the Recent New Zealand species *Litsea calicaris* (Fig. 1.3) have been reported from Ormond, Poverty Bay (Oliver, 1928). No other New Zealand fossils have been assigned to this genus.

### ?*Litsea dawsoniana* sp. nov. (Figs. 1.1, 1.2)

Mesophyll, at least 90 mm long by 55 mm wide; symmetrical, elliptic; apex obtuse to emarginate, sometimes splitting along midrib; base missing in all specimens; margin entire, plane or recurved; venation pinnate, brochiodromous, loops close to margin; midrib weak to moderate, straight, secondaries opposite to alternate, at least seven pairs, spacing rather distant below becoming crowded above, angle of divergence narrow to moderate,  $45^{\circ}$  to  $60^{\circ}$ , more or less uniform, rather thick, somewhat curved, sometimes branched, joining superadjacent at acute angle, enclosed by secondary arches; intersecondaries compound; tertiaries percurrent, forked, convex or retroflexed, diverging at acute angle from lower and obtuse angle from upper side of secondary, oblique to midrib, approaching horizontal towards margin, predominantly alternate, thick, c. 2.5 mm apart, fine venation not well differentiated, random to orthogonal, rather weak; areoles well-developed, more or less orientated, small, pentagonal possibly with unbranched veinlets.

The venation pattern described is found in a number of genera of the Lauraceae, particularly *Litsea*, *Cryptocarya* and *Endiandra*, all common in rain forests in Australia, New Caledonia and Polynesia. The Longford fossils resemble most closely *Litsea lefiana* (F. Muell.) Merr. and to a lesser extent *Cryptocarya corrugata*, both from Queensland, but are larger than specimens in the herbarium at the National Museum. The fossil identified as *Ficus subsimilis* by Ettingshausen (1887) resembles the Longford *Litsea dawsoniana* and may not belong to *Ficus*.

**Holotype:** VH105, VUW; Longford Formation, Mid to Upper Miocene; Dress Circle, Longford, M29/579347 NZGS; Brett Dawson, 1979.

**Paratypes:** B2/39 and B2/40 (counterparts), NZGS; Nuggety Creek, M29/604410; R. P. Suggate *et al.* VH106, VUW; Glenroy River, upper Matakitaki Valley, M30/550113, NZGS; A. M. Holden and J. D. Collen, January 1979.

**Other material examined:** V2830 from Nuggety Creek and V2838 from Glenroy, both VUW; A. M. Holden and J. D. Collen, 1979. All specimens from the Longford Formation.

The species is named after the collector of the holotype.

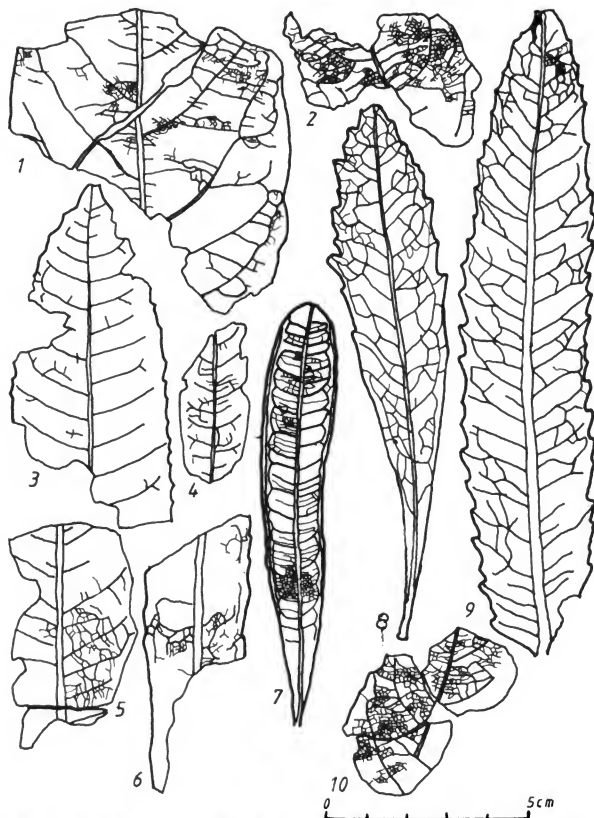


Fig. 3—Proteaceae. 1, 2, 10 — *Kermadecia merytifolia* sp. nov. (1: VH109, holotype; 2: B7/63; 10: VH110). 3, 4, 5 — *Knightia oblonga* Oliver (3: B2 18; 4: B7 66; 5: Vh 108). 6 — *Longfordia banksiaefolia* gen. et sp. nov., B2 50, holotype. 7 — *Banksia* sp., ex Hort., Wellington. 8 — *Telopea speciosissima* R. Brown ex Hort., Wellington. 9 — *Knightia excelsa* R. Brown, Newlands, Wellington.

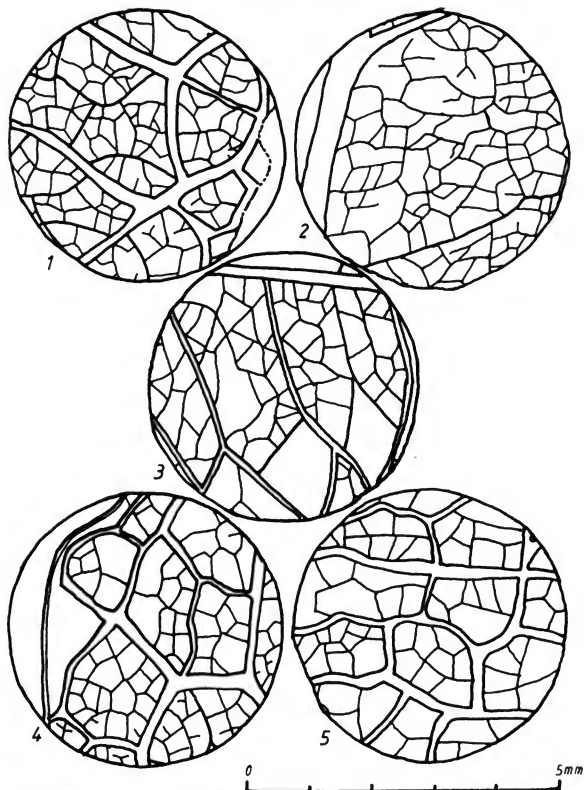


Fig. 4—Proteaceae. Camera lucida drawings of fine venation. 1, 2 — *Kermadecia merytifolia* (1: near margin; 2: mid lamina). 3 — *Knightia oblonga*, mid lamina, ?juvenile. 4 — *Knightia excelsa*, marginal, adult. 5 — *Banksia* sp.

## FAMILY PROTEACEAE

The recent New Zealand flora contains two members of the Proteaceae, *Knightia excelsa* R. Brown and *Toronia toru* (A. Cunn.) Johnson and Briggs (Allan, 1961). Both are endemic. *Toronia* was formerly included in the Australian genus *Persoonia* Smith, and *Knightia* is related to two New Caledonian species now separated as *Eucarpha* (Johnson and Briggs, 1975). Pollen of proteaceous type has been found in New Zealand from the Upper Cretaceous onwards (Couper, 1960), and the family appears to have been represented by more species during the Tertiary than at present.

In the Proteaceae, leaf form is extremely variable (Virox, 1968; Johnson and Briggs, 1975) and the occurrence of different juvenile and adult forms in some genera makes identification of the fossils difficult. Ettingshausen (1887, 1891) described three species of Cretaceous and early Tertiary Proteaceae: *Knightiophyllum primaevum*, *Dryandroides pakawaia* and *Dryandra comptoniaefolia*. Of these, *Knightiophyllum primaevum* resembles neither *Knightia* nor any of its close relatives, and the affinities of *Dryandroides pakawaia* are unclear. Three genera are recognised from the Longford Formation: *Knightia*, *Kermadecia* and the extinct *Longfordia*.

***Knightia* R. Brown**

Living species, a tall tree of closed and second-growth forests. Leaves simple, dimorphic, those of juveniles thinly coriaceous, linear lanceolate, occasionally forked or pinnately lobed, acutely serrate; adults thick, coriaceous, simple, narrow oblong, bluntly and coarsely serrate; venation pinnate, craspedodromous, usually with branches joining superadjacent to form irregular loops, vein running to apex of tooth; intersecondaries compound; tertiaries reticulate, more or less random. Highest order venation 5°; fine venation random to more or less orthogonal, that of juveniles more random with less differentiation of vein orders; areoles perfect, more or less orientated, triangular to pentagonal, somewhat small, those of juveniles larger and sometimes incomplete.

*Type species: Knightia excelsa* R. Brown, New Zealand.

Pollen attributed to *Knightia* is known from the Upper Cretaceous onwards (Couper, 1960) and macrofossils from the Miocene and Pliocene (Oliver, 1928; 1936). The status of *Knightiophyllum primaevum* Ett. has been discussed. Outside New Zealand, *Knightia* has been recorded in fossil form from Australia (Ettingshausen, 1888) and from Seymour Island, Antarctica (Dusen, 1908). Species of *Knightiophyllum* reported from the Eocene of southeastern North America have been discounted (Dilcher and Mehrotra, 1969).

***Knightia oblonga* Oliver, 1936 (294: fig. 12) (Figs. 3.3, 3.4, 3.5, 4.3)**

Mesophyll, leaves at least 100 mm long and up to 40 mm wide; narrow oblong to more or less linear; apex bluntly acuminate; base not preserved, margin toothed, serrate-dentate, teeth acute, simple, straight-sided, sinus rounded, spacing more or less uniform; midrib moderate to stout, straight; secondaries at least 12 pairs, subopposite to alternate, diverging at wide to more or less right angle, weak; higher-order venation rather poorly preserved, random; areoles triangular to pentagonal.

The Longford fossils correspond closely to Oliver's type specimen from Kaikōrai. The published illustration (Oliver, 1936: fig. 12) is not good. There is also a marked resemblance to *K. fassilis* Oliver (Pleistocene) from Ormond, Poverty Bay, which was synonymised with the living *K. excelsa* (Figs. 3.9, 4.4) by McQueen (1954). The Longford fossils differ in being broader than is usual for *K. excelsa*, with smaller, more regular marginal teeth. The margins of some of the specimens are badly eroded, and the texture of the leaf appears to have been thinner. These are probably juvenile forms.

*Holotype*: WELT. 44546 in the National Museum, Wellington; Upper Miocene, Kaikōrai; W. R. B. Oliver, 1936.

*Figured specimens*: B2/18 (M29/f8579), Nuggety Creek; B7/66 (M29/f8606), Dress Circle, Longford, M29/579347; VH108 (M29/f149), Blue Duck Creek, M29/616404, A. M. Holden and J. D. Collen, 1979.

*Other material examined:* B7/76 (M29/f8606), Dress Circle, Longford, M29/579347, S. M. Bell and R. P. Suggate, 1949.

***Kermadecia* Brongn. & Gris.**

Living species trees, mainly of closed forests. Leaves bi- or tri-morphic, juveniles variously lobed to pinnatisect, sometimes more or less pinnately compound, adults simple, margins entire, sometimes rather irregular; venation pinnate, brochiodromous with enclosing secondary and tertiary arches; secondaries often branched; tertiaries percurrent; highest-order venation 5th or 6th; fine venation more or less random; areoles generally perfect, more or less random, triangular to polygonal, somewhat small.

*Type:* *Kermadecia elliptica* Brongn. and Gris, New Caledonia.

There is no previous living or fossil record of *Kermadecia* in New Zealand.

**?*Kermadecia merytifolia* sp. nov. (Figs. 32., 3.2, 3.10, 4.1, 4.2)**

Mesophyll, probably c. 130 mm long, width 70 mm; somewhat broadly oblong; apex and base missing; margin entire, more or less undulate; venation pinnate, brochiodromous with enclosing secondary and tertiary arches; midrib moderate to stout, c. 2.6% of lamina width, straight, longitudinally striate; secondaries alternate, irregularly spaced 15 to 25 mm apart, diverging at narrow to moderate angle, somewhat more acute on one side than other, moderately thick, curved, with branches arising from lower sides of secondaries, branches and secondaries arching round to join superadjacent at acute angle forming angular loops; tertiaries diverging at acute angle from lower and obtuse angle from upper side of secondaries, percurrent, straight or sinuous, more or less horizontal, some recurved, moderately thick, alternate. Highest-order venation 6th; fine venation somewhat random, rather thick; areoles quadrangular to polygonal, perfect, more or less random, fairly large, sometimes with simple or branched veinlets.

The fossils superficially resemble leaves of a small form of *Meryta sinclairii* (Hook. f.) Seem. (Araliaceae), but the venation of the fossil is clearly brochiodromous while leaves of *Meryta* are generally craspedodromous. They strongly resemble the adult leaves of *Kermadecia elliptica* Brongn. and Gris and *K. sinuata* Brongn. and Gris, which both show a similar pattern of secondary branching and more or less horizontal tertiaries.

*Holotype* VH109 (M29/f154), Dress Circle, Longford, M29/579347; A. M. Holden and J. D. Collen, 1979.

*Other material examined:* B7/36, B7/63 (both M29/f8606), Dress Circle, Longford, M29/579347, S. M. Bell and R. P. Suggate, 1949; VH110 (L30/f31), Rappahannock, L30/474037, A. M. Holden and J. D. Collen, 1979.

The species is named after *Meryta sinclairii* (Hook. f.) Seem., which the fossil leaves resemble.

***Longfordia* gen. nov.**

Leaf narrow oblong to linear; margin serrate; venation pinnate, camptodromous; midrib stout to massive; secondaries weak; irregularly spaced; tertiary venation reticulate, more or less random, weak; fine venation not well differentiated into vein orders, somewhat random; areoles small.

*Type species:* *Longfordia banksiaefolia* sp. nov.

***Longfordia banksiaefolia* sp. nov. (Fig. 3.6)**

Leaf more or less linear, 27 mm broad; apex and base missing; margin coarsely and irregularly serrate, teeth straight-sided, more or less acute, rather distant; venation pinnate, camptodromous; midrib stout to massive, c. 4% lamina width, secondaries weak, diverging at wide to more or less right angles, 70 to 90°, somewhat sinuous, possibly forming a series of flat arches; tertiaries diverging at right angles, more or less random reticulate; higher-order venation random to more or less orthogonal, obscure.

The fossil superficially resembles a juvenile leaf of *Pseudopanax crassifolium* (Sol. ex A.



Cunn.) C. Koch. but has a different venation pattern which is consistent with that of many Proteaceae. Several genera of the Proteaceae, for example *Banksia*, *Macadamia* and *Orites*, show elongate, toothed leaves of this type.

*Holotype*: B2/50 (M29/f8579), Nuggety Creek, M29/604410, R. P. Suggate, D. Kear, E. T. Annear, and W. A. Sara, 1951.

The specific name alludes to the resemblance of the fossil to leaves of some species of *Banksia*.

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